1983

Soil Detection using Panchromatic and Infrared Films

Bruce O. Kunze

SOIL DETECTION USING PANCHROMATIC

AND INFRARED FILMS

BY

Bruce O. Kunze

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science
Major in Agronomy

South Dakota State University
1983

SOIL DETECTION USING PANCHROMATIC

AND INFRARED FILMS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Gary D. Lemme Date
Thesis Adviser

Maurice L. Horton Date
Head, Plant Science Department

Douglas D. Malo Date
Major Adviser

ACKNOWLEDGEMENTS

It is difficult to give the appropriate recognition to all of the people who assisted in the author's graduate work and in this study. The author owes a special thanks to his major advisor, Dr. Doug Malo, and his thesis advisor, Dr. Gary Lemme, for their counsel, patience, and guidance throughout the graduate program and for their assistance and valuable suggestions concerning the research and completion of this thesis.

The author is deeply indebted to the Soil Conservation Service, especially Robert Swenson, Miles Smalley, and Charles Peterson for their generous assistance and support in the completion of this work. Gratitude is also expressed to the staff of the Remote Sensing Institute for technical assistance and use of their equipment.

The author is grateful to Dr. Fred Westin and Dennis Heil for initiating the study and collecting ground truth. Special thanks is extended to Dr. William Tucker and Dr. Paul Evenson whose aid with the statistical portion of this project was indispensable. Appreciation is expressed to Corrine Ehlers and Cathy Haan for their valuable assistance in assembling this manuscript.

The author is forever indebted to his parents for their nurture and encouragement throughout his academic endeavors. This manuscript is dedicated to my wife, Wanda; without her love, devotion, and sacrifices this work could never have been completed.

-- bok

TABLE OF CONTENTS (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

APPENDICES

APPENDICES

APPENDICES

Soil Detection Using Panchromatic and Infrared Films

B. O. Kunze

ABSTRACT

Efforts have been made in the soil survey program to improve soil mapping quality. Three types of aerial films were tested to determine if tonal differences exist among the three film types either singularly or in combination which would allow discrimination of soil series within a landscape across several land covers. The imagery consisted of panchromatic (600-700 nm), panchromatic (500-700 nm), and black and white infrared (700-900 nm). The utility of these film types for discrimination of the components of soil mapping unit complexes was also tested.

Differences were detected between films in the accuracy of discriminating soils due to land cover. The panchromatic (600-700 nm) film appeared to be most useful in areas with no land cover, crop residue, and small grain. In areas planted to alfalfa, the greatest accuracy was obtained using panchromatic (600-700 nm) or (500-700 nm) film. Generally, the infrared (700-900 nm) appeared to be most useful in areas used for pasture where reflectance characteristics of the grasses are contrasting.

Combinations of films improve accuracy in discriminating soils, in areas with no land cover and no crop residue. The combination of panchromatic (600-700 nm) and panchromatic (500-700 nm) films were most useful in improving accuracy on landscape units with no land cover. Combinations of the panchromatic (600-700 nm) and infrared (700-900 nm)

films were useful within soil groupings with more contrasting soil components. Over-all accuracy in discriminating soils was greater for soils within mapping units than for landscapes.

INTRODUCTION

The need for quickly obtained soil and vegetation information at a reduced cost of data acquisition has resulted in increased interest in the use of remote sensed soil and plant reflectance data. The spectral signature of a landscape depends on the spectral properties of the soil and plant cover present. Spectral signatures of unvegetated landscapes are a function of soil color, organic matter content, mineralogical composition, texture, surface structure, and moisture content. Reflectance from vegetated landscapes is a function of leaf structure, shape, size, and orientation; crop species, variety, maturity, and geometric configuration; crop vigor; soil and plant moisture content; chlorophyll content; canopy cover; and background soil reflectance. Data obtained using remote sensing techniques are useful in distinguishing soil groupings from one another for soil surveys and have been used with limited success in computer assisted soil mapping. Aerial photography with more contrast between soil series on vegetated and unvegetated landscapes would help improve the quality of and speed of producing soil survey maps.

The objectives of this study were to (1) determine if tonal differences measured as film transmission data exist among the three film types either singularly or in combination would allow discrimination of soil series within a landscape separated into several land cover types and (2) evaluate the utility of these film types for the discrimination of the components of soil mapping unit complexes. Most previous comparisons of panchromatic with infrared films for soil series discrimination in agriucltural areas were conducted in areas with no vegetative cover.

LITERATURE REVIEW

Soil Reflectance

Color is an easily recognizable soil characteristic. Slight differences in soil surface color are used in classifying soils at different levels of taxa (Westin and Lemme, 1978; Lewis et al., 1975; Soil Survey Staff, 1975). Unless there is a greater than 40 percent finely divided lime in both broken and crushed samples, a mollic epipedon has a Munsell color value darker than 3.5 moist (5.5 dry) and chroma less than 3.5 moist (Soil Survey Staff, 1975) whereas, an ochric epipedon has a value or chroma that is too high to qualify for mollic epipedon. Munsell color notation is expressed in terms of hue, value and chroma (Munsell Color Company, 1947). Hue is the dominant spectral color. Value refers to the relative lightness of color and is a function of the total amount of light. Chroma is the relative purity of the spectral color. Soil color is a function of absorption in the visible region of the electromagnetic spectrum.

Some soils can be distinguished from one another by their color and intensity of reflection in wavelengths senesed by the human eye. Additional information can be obtained using detectors sensitive to energy reflection beyond the visible spectrum (Myers and Allen, 1968). The spectral reflectance of a soil surface is determined by several factors including organic matter content, iron oxide content and oxidation state, mineralogical composition, moisture content, and soil structure (Myers et al., 1966).

Obukhov and Orlov (1964) reported that minimum reflectance of the unvegetated surface soils studied was in the blue-violet (400 nm) portion of the spectrum. For example, reflectance in blue part of the spectrum ranged from 13 percent for the A horizon of a thick Chernozem to 18 percent for the A horizon of a Sod-podzolic soil. Maximum reflection in the visible part of the spectrum was in the red (700 nm) region of the spectrum. Reflectance of the same samples ranged from 17 percent for the thick Chernozem to 44 percent for the Sod-podzolic soil. The greatest difference between soils is observed in the red region of the spectrum making it the most useful for discrimination between soils using soil reflectance data. Obukhov and Orlov stated that a parent material generally has higher reflectance than the soil that develops in it mainly because of lack of organic matter accumulation.

Condit (1970) measured spectral reflectance of 160 surface soils from 36 states, in the 300 to 1000 nm wavelengths using a recording spectrophotometer. Each sample was measured at two moisture contents: just less than saturation and oven-dry. The data from these soils fit into three general spectral reflectance curve shapes.

Stoner and Baumgardner (1981) found five distinct soil spectral reflectance curves when 485 uniformly moist surface soil samples were analyzed. The samples, representing 246 soil series from 39 states and Brazil, were studied in the 520 to 2320 nm wavelength range with a spectroradiometer adapted for indoor use. These five soil spectral reflectance curves could be distinguished as having common characteristics, mainly organic matter content and iron oxide content. Other characteristics often associated to the reflectance curves were texture, natural drainage, and mineralogy. Reflectance spectra representative of the five curve forms are illustrated by five mineral soils in (Figure 1). Curve (a) exhibits low overall reflectance with a characteristic slightly concave curve from 500 to 1300 nm. Strong water absorption bands are present at 1450 and 1950 nm in this and most other curve forms. Generally, the soils in this curve group have greater than two percent organic matter, less than one percent iron oxide, good to poor natural drainage, fine to moderately fine textures, and montmorillontic mineralogy. Curve (b) typically has a higher over-all reflectance than curve (a). It exhibits a concave shape from 500 to 750 nm with a convex shape from 750 to 1300 nm. Soils in this curve group generally have greater than two percent organic matter, less than one percent iron oxide, medium to coarse soil textures, good to poor natural drainage, and mixed mineralogy. Curve (c) has the highest reflectance of the five mineral soils. Curve (c) has a convex curve shape from 500 to 1300 nm with strong water absorption bands at 1450 and 1950 nm. Soils in this curve group generally have less than two percent organic matter, less than one percent iron oxide, good natural drainage, variable soil texture, and mixed mineralogy. Curve (d) is distinguished by a slight ferric iron absorption band at 900 nm and strong water absorption bands at 1450 and 1950 nm. Soils in this curve group generally have less than two percent organic matter, one to four percent iron oxide, variable soil texture, good natural drainage,

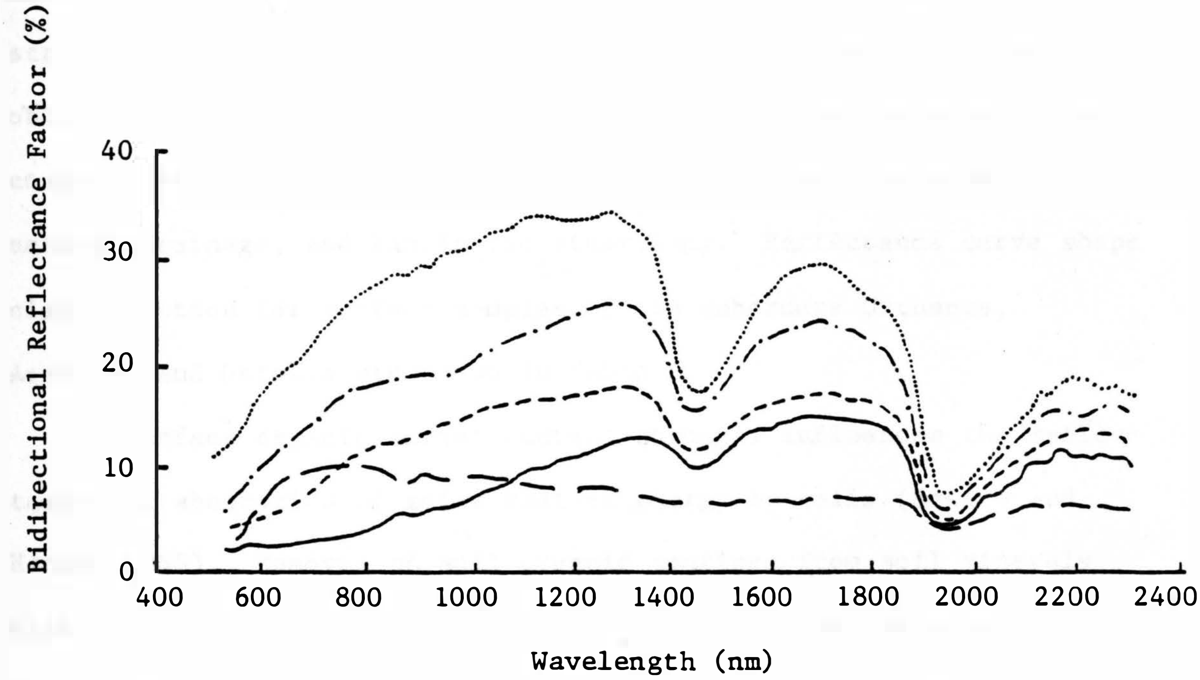


Figure 1. Representative reflectance spectra of surface samples of 5 mineral soils (Stoner and Baumgardner, 1981).

and mixed mineralogy. Curve (e) is unique in that reflectance actually decreases with increasing wavelength beyond 750 nm. Reflection decreases due to absorption of radiation by iron oxide. Absorption by iron oxide in the middle-infrared wavelengths is so strong that the 1450 and 1950 nm water absorption bands are nearly obliterated. Generally soils in this group have varied organic matter content, greater than four percent iron oxide, fine textures, good natural drainage, and kaolinitic mineralogy. Reflectance curve shape classification for surface samples of the suborders Orthents, Aquolls, and Ustolls are shown in Table 1.

Surface organic matter content strongly influences the reflectance and absorption of solar radiant energy by soils (Bowers and Hanks, 1965). Removal of soil organic coatings from soil minerals with 30% H_2O_2 increased the reflectance for all samples measured. Bowers and Hanks reported that 8.2 percent more energy was reflected by oxidizing the organic matter present in a Newtonia (fine-silty, mixed, thermic Typic Paleudolls) silt loam when compared to an unoxidized surface sample with 1.4 percent organic matter. Latz et al. (1981); Frazee et al. (1972), and Westin (1975) reported eroded soils in the field have greater spectral reflectance than noneroded soils due to a decrease in organic matter and moisture content.

Surface soil reflectance measurements were made on a Netonia silt loam at gravimetric moisture contents ranging form 0.8 to 20.2 percent (Bowers and Hanks, 1965). Soil samples were purified using a 20 mesh seive and packing the soil into cylinders. Reflectance decreased in a linear relationship as the surface moisture content

Table 1. Reflectance curve shape classification for surface soil samples of the suborders: Ortherts, Aquolls, and Ustolls (Stoner and Baumgardner, 1981).

	Reflectance Curve Shape					
Suborder	a	b	c	d	e	Samples
Orthent	0	8	12	2	0	22
Aquolls	23	4	1	0	0	28
Ustolls	34	20	8	2	0	64

increased at all wavelengths. The most contrasting aerial photographs can be obtained at a low soil moisture content (Obukhov and Orlov, 1964).

Many times when correlations have been found between soil moisture content and photo density of bare soils, soil color and moisture content were closely related to the organic matter content (Evans, 1979). Increasing organic matter content is associated with more soil moisture and darker soil colors. This correlation is inherently due to darker colors of soils with more organic matter, rather than to increase in moisture content.

Bowers and Hanks (1965) measured the reflectance of clay minerals in the 22 to 2680 micron particle size range over the wavelengths of 400 to 1000 nm. An exponential increase in reflectance was measured with decreasing particle size. The most noticeable reflectance increase occured between particle sizes of 400 to 22 microns.

Gerbermann (1979) measured reflectance of fabricated sand-clay soil mixtures containing sand levels ranging from 0 to 100 percent in the 440-860 nm wavelength region. The Ap horizon of a Harlingen (<u>very fine, montmorillontic, hyperthermic Entic Chromusterts</u>) clay soil was separated into sand, silt, and clay fractions using a dispersing agent and sedimentation. The sand-clay soil mixtures were prepared by adding sand to the original soil sample for the mixtures containing 10 to 90 percent sand. The Munsell value for the 100 percent clay and the 100 percent sand samples were 5.5 and 7, respectively. An increase in reflectance results from an increase in percent sand in the sample at all wavelengths tested. As the sand level increased, the quantity of sand required to give a significantly higher percent reflectance decreased. The percent reflectance for all levels of sand increased as wavelength increased.

Myers and Allen (1968) and Obukhov and Orlov (1964) reported that the effect of particle size on reflectance of pulverized soil samples measured by a spectrophotometer may be misleading. Most laboratory studies of pulverized soil indicate that increasing particle diameter results in decreased reflectivity. This conclusion is only correct for laboratory dispersed soils. The artificial breakdown of aggregates usually results in increased reflectance due to the particles filling the volume more completely forming a more even surface. However, in aerial photos, fine textured soils have a darker tone than coarser textured soils with the same organic matter content. Myers and Allen (1968) stated that reflectance measurements of undisturbed soils in the field are generally opposite those measured in the laboratory.

Hovis (1966) measured the spectral reflectance of common minerals in the 500 to 2500 nm wavelengths. Reflectance of silica sand has a linear increase from 45 to 60 percent over the wavelengths from 500 to 1000 nm respectively. Pure carbonate has a reflectance of 90 to 95 percent over the wavelengths of 500 to 1000 nm.

Vegetation Reflectance

The intensity of near-infrared radiation from vegetated surfaces is a function of leaf shape, size, and orientation and canopy density (Gates, 1965). The spectra of a leaf is characterized by absorption in the 380 to 700 nm wavelength region primarily due to chlorophyll absorption (Gates et al., 1965; Knipling, 1970; Moss and Loomis, 1951; Myers et al., 1966) (Figure 2). Maximum absorption occurs in the blue and red part of the spectrum at 470 and 680 nm respectively. The familiar green reflectance peak occurs at 550 nm. The highest reflection by plants occurs in the near-infrared part of the spectrum between 700 and 1300 nm. Thick, heavily pigmented leaves show a high absorption across the entire visible spectrum, with absorption bands less clearly defined (Moss and Loomis, 1951). Yellow and orange leaves show greater reflectance of green light than green leaves. Mean absorption values of 92, 71, and 84 percent were found for beans (<u>Phlaseolus vulgaris</u>), spinach (<u>Spinacia oleracea</u>), swiss chard (<u>Beta vulgaris</u>), and tobacco (<u>Nicotiana tabacum</u>) leaves in the spectral regions of 400 to 500, 500 to 600, and 600 to 700 nm respectively. The reflection of a plant canopy is similar to that of individual and stacked leaves but is modified by the non-uniformity of incident radiation, plant structures, leaf area, shadows, and background reflectance (Colwell, 1974 and Knipling, 1970). Airborne sensors receive an integrated view of all these effects. Each crop tends to have a characteristic spectral signature which permits discrimination between crops when significantly different. However, for grasses, one plant is frequently indistinguishable from others in the proximity (Colwell, 1974). Reflectance of a grass canopy is dependent not only on individual plants, but also on inter-plant characteristics such as plant density and degree of leaf overlap. Red reflectance of grass canopies is negatively correlated to percent vegetative cover with light-toned soil backgrounds, but was uncorre-

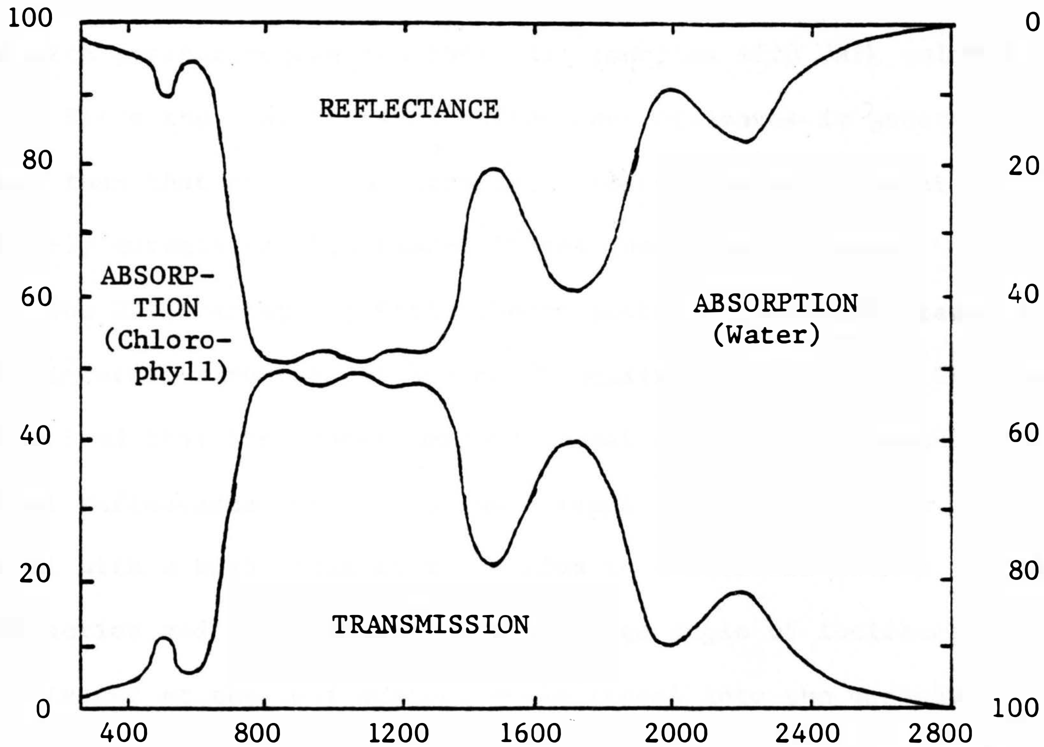


Figure 2. Reflectance, absorption, and transmission spectra of a plant leaf (Knipling, 1970).

lated to percent vegetative cover when the grass canopies had dark soil background. Green reflectance is negatively correlated with percent vegetation cover for light colored soils and positively correlated with percent vegetation cover for canopies with dark colored soils. Since the near-infrared reflectance of leaves is generally greater than that of soil background, percent vegetation cover is positively correlated with near-infrared canopy reflectance.

The Willstatter and Stoll theory explains leaf reflectance based on the internal structure of leaves (Sinclair et al. 1973). The theory hypothesized that the spongy mesophyll best met the requirements for critical reflectance due to (1) the passage of radiation from a material with a high index of refraction to a material with a low index of refraction and (2) the sufficiently large angle of incidence. Light not reflected at the leaf surface would travel into the mesophyll.

The reflectance spectra from 500 to 2600 nm were measured for the leaves of soybeans (Glycine max), corn (Zea mays), wheat (Triticum aestivum), oats (Arvena sativa), sorgum (Sorghum bicolor), and sudangrass (Sorghum sudanense) using a spectrophotometer (Sinclair et al., 1971). Leaf samples were collected at three periods during the growing season. Water content was determined and a cross section of the leaf was observed microscopically. The reflectance spectra of all fresh green leaves were very similar. However, reflection at all wavelengths increased as the crop matured and their leaves senesce. Decreased absorption of chlorophyll apparently increased the reflectance of the visible wavelengths from 500 to 700 nm. Changes in the internal structure of leaves and lower moisture content caused increased reflection in the near-infrared wavelengths (700 to 1300 nm) due to the collapse of internal leaf structures. Water loss accompanying senescence resulted in an increased reflectance in the far infrared wavelengths (1300 to 2600 nm).

Sinclair et al. (1973) measured spectral reflectance of corn and soybean leaves throughout the 500 to 2600 nm wavelength region. The two sides of the corn leaf did not differ significantly in spectral reflectance in the near-infrared region. The ventral side of the soybean leaf reflected significantly higher levels of near-infrared radiation than did the dorsal side. The palisade cells contributed to the scattering of near-infrared radiation in dicotyledonous plants.

Gates et al. (1965) reported that plants absorb light very efficiently throughout the visible part of the spectrum where energy is used for photosynthesis. However, for wavelengths longer than those of the red chlorophyll absorption band, the reflectance and transmission of plant leaves increase dramatically resulting in a low rate of absorption. This occurs precisely throughout the frequency range where direct sunlight incident on plants has the bulk of its energy. A fully mature leaf has a cell structure and intercellular space favorable to increased reflectance in the infrared and reduced reflectance in the green part of the spectrum. Visible light reflectance increased for light colored leaves.

The infinite reflectance of dead and live corn leaves over the 500 to 2500 nm waveband was tested to find a means of distinguishing dead from live leaves (Gausman et al. 1976). Reflectance measurements were made on a single leaf section and for sections of stacked leaves over the spectrophotometers port. Infinite reflectance for live leaves was reached by stacking two leaves for the 500-750 nm waveband, eight leaves for the 750 to 1350 nm waveband, and three leaves for the 1350 to 2500 nm waveband. For dead leaves infinite reflectance was obtained by stacking only two or three leaves over the entire 500 to 2500 nm waveband.

Tucker et al. (1979) collected red and near-infrared reflectance data to monitor corn and soybean growth and development. A hand held radiometer was used at a 4 to 12 day interval throughout the growing season. The red reflectance of soybeans decreased rapidly with time because of increased chlorophyll absorption caused by increased green-leaf biomass until the bloom stage. Reflectance remained fairly constant until senescence began. At this time, red reflectance began to increase as the chlorophyll level in the plant canopy declined due to chlorophyll breakdown and/or leaf loss. The near-infrared reflection increased with time and green-leaf biomass. This increase was gradual and peaked at full bloom then gradually declined as the growing season ended. The normalized difference transformation was used to effectively compensate for variations in environmental conditions. With this data plotted against time, green-leaf biomass dynamics were compared between crops. The linear combinations of red and near-infrared wavelength intervals were highly correlated to green-leaf biomass. The infrared/red ratio was found to be more sensitive to green-leaf biomass than to the green/red ratio. The infrared/red ratio, square root of infrared/red ratio, infrared-red difference, vegetation index and transformed vegetation index were similar in sensitivity to the photosynthetically active vegetation present in the plant canopy (Tucker, 1979).

Soil-Plant Interaction

Aase and Siddoway (1980) used a hand held radiometer with wavebands comparable to Landsat multispectral scanner bands 4, 5, 6 and 7 to measure wheat seedling canopy covers of 0, 10, 20, 40, 60, 80 and 100%. The experiment was designed to determine if winter kill could be detected by Landsat multispectral scanner. The plots were located on Williams (fine-loamy, mixed Typic Ariborolls) loam. Normalized difference vegetation index V17 = (MSS7 - MSS5)/MSS7 + MSS5) with a variant of substituting MSS6 for MSS7 was used to illustrate crop canopy differences. Early in the season, V17 separated stand of 40 percent or more from stands of less than 40% crop cover allowing a judgement as to whether or not a field should be reseeded to a spring crop. The 10 to 20 percent stand plots became distinguishable from the soil background at a biomass accumulation of about 30 kg/ha or leaf area index of about 0.06.

Colwell (1974) measured the reflectance of a green oats canopy versus a dead oat canopy with similar percent cover. Near-infrared hemispherical reflection for individual leaves increased from 47 percent for live leaves to 59 percent for dead leaves. The canopy reflectance, however, only changed from 37 percent reflectance for live vegetation to 40 percent reflectance for dead vegetation. Therefore, changes in near-infrared leaf reflectance versus dead leaves compensates for each other in their effect on canopy reflectance. For the same canopy, the red hemispherical reflectance increased from 6 percent reflectance for live leaves to 56 percent reflectance for individual dead leaves. The canopy reflectance increased from 4 percent reflectance for live vegetation to 37 percent reflectance for dead vegetation. The data indicates that live vegetation is easier to distinguish from dead vegetation using the red region of the spectrum than the near-infrared region of the spectrum.

Leamer et al. (1978) followed the changes in the reflectance of two dissimilar wheat cultivars (winter wheat and spring wheat) through a growing season to determine their reflectance characteristics. Reflectance over the wavelength intervals of 450 to 2500 nm was measured with a ground based spectrometer on Hidalgo (fine-loamy, mixed, hyperthermic Typic Calciustolls), sandy clay loam soil. All reflectance curves had the characteristic shape for a vegetated surface 4 weeks after crop emergence and about 25% ground cover was attained. The proportion of the ground covered by plants was more important than development stages of the plant.

Suits (1983) modified the uniform canopy reflectance model to include row effects using density modulation in such a way as to reduce the row effect to the uniform canopy model as row structure disappears from the canopy due to canopy closure. The direction of sunlight relative to the row direction will change the relative influence of vegetation and bare soil. When the sun is directly along the row direction, the bare soil is fully illiminated but when the sun is directed across rows, the soil is largely in the shadow of the standing vegetation. Suits states that the red waveband, Landsat band 5, is most sensitive to row direction because of the unusual large contrast between vegetation and soil. Reflection in this band may easily vary by a factor of two with changing row direction. The near-infrared bands, Landsat 6 and 7, are least affected by row direction because of low contrast between soil and vegetation and because of large amount of diffuse radiation scattered to soil by the vegetation. The impact of row direction and Landsat signals from across-row and down-row wheat fields was estimated for a 45° sun angle. The resulting MSS 7/MSS 5 ratio was 2.0 for across-row direction and 1.33 for down-row direction. The down-row direction gives an indication of a much less vigorous growing field than the across-row direction.

Gausman et al. (1975) measured reflectance spectra of bare soils and of soils with standing and littered sugarcane (*Saccharum officinarum*) residue. Littered crop residue had higher reflectance than bare soil, but standing crop residue had lower reflectance than bare soil. The bare soil and littered residue had the same hue and chroma but the littered residue had a slightly higher value than the bare soil. The spectral composition of the scene viewed is a function of the number of shadows, the height of the standing residue, the amount of sunlit bare soil, and the amount of crop residue and its degree of decay.

Gausman et al. (1977) compared field measured spectroradiometer reflectances of nondisked bare soil with or without littered wheat straw and bare soil that was disked directly or after littering of wheat straw. The experiment was on a Hidalgo sandy loam. The near-infrared region (750 - 1300 nm) seemed better than the visible region

(450 - 750 nm) for distinguishing among reflectances of soil-tillage-straw treatments. Reflectance of nondisked bare soil and disked soil with the low straw treatment were statistically similar.

Remote Sensing of Crops and Soils

Soil association maps have been produced using multispectral scanner (MSS) data. Westin and Myers (1973) revised the soil association map of South Dakota using Landsat multispectral scanner (MSS) data. Band 5 (600–700 nm) gave the best soil contrast and clearest image while band 7 (800–1100 nm) appeared most useful in detecting vegetative vigor. Shallow, less productive rangelands normally had a higher reflectivity than rangelands with deeper more productive soils using band 7 due to a denser canopy cover.

Westin and Frazee (1976) produced a low intensity soil survey of Pennington County, South Dakota using Landsat bands 4, 5, 6 and 7 individually and as a color composite of bands 4, 5, and 7. Areas of similar spectral characteristics were delineated. Ground truth was collected on soil, vegetation, geologic features, and other surface features responsible for reflectance patterns. More soil associations were delineated using Landsat imagery than were delineated on the pre-existing soil association map.

Lewis et al. (1975) used Landsat multispectral scanner imagery to develop a soil association map of the Nebraska Sand Hills. Relationships established between published soil association maps and satellite imagery were used to identify soil associations in an adjacent area within the Sand Hill region. MSS band 5 and color composites generated from MSS bands 4, 5, and 6 were useful in stratifying the soil associations in the area.

Computer pattern recognition techniques were used to investigate relationships of Landsat multispectral data to soil patterns under range vegetation in a semiarid region (Kornbaum and Cipra, 1983). Order two soil maps of the study area using eleven mapping units were developed prior to computer analysis using conventional soil survey methods. The mapping units, included eight consociations and three complexes, were mapped at the family or soil series level. Supervised and "cleaned" supervised computer assisted clustering methods were used to classify Landsat digital spectral values into the eleven possible mapping units and produce a computer classification map. The over-all percent agreement was 32.8 and 46.5 percent for the supervised and "cleaned" supervised methods respectively.

The Landsat spectral properties were investigated for six soil associations in Brookings County, South Dakota (Westin and Lemme, 1978). Landsat data for April 19 and June 30 were used to assess the influence of soil association on the spectral signatures of vegetation and bare soil. Soil differences had a more pronounced influence on spectral properties with grassland than with cropland. The June data showed that soil associations could not consistantly be separated but that soil properties did influence vegetative spectral reflectances to some degree. A wide range in MSS band 5 values indicated that photosynthesis varies greatly within the grassland data. Grassland in poor condition due to over grazing and stress would have a higher reflectance than grass growing under normal conditions. Westin and Lemme were able to identify four soil associations within the June Landsat data on corn with an overall accuracy of 70 percent using a K-class computer program.

Kumar and Silva (1977) used airborne multispectral scanner data obtained on July 16 and August 12 to determine statistical separability of corn, soybeans, green forage (hay and pasture), and forest. Over-all separability of green forage from the other agricultural cover types was found to be lower than separability of corn, soybeans, and forest because much natural variability existed in the spectral characteristics of hay and pasture. Green forage and corn were extremely hard to separate using the July 16 data because of considerable overlap in the values of their mean response due to the extremely large standard deviation of the green forage reflectance. The greatest over-all separability of agricultural crops using a single waveband was achieved using the red (600–700 nm) waveband. This may be due to significant differences in the chlorophyll content of different agricultural crops. The reflectance in the near-infrared region is most useful when substantial difference in percent ground cover exist between agricultural cover types.

An airborne multispectral scanner with eleven wavelength bands was used as an aid in a detailed soil survey area with Mollisols and Alfisols (Kristof and Zachary, 1974). The study area consisted of Wisconsin age glacial till, outwash, and eolian deposits. Bare soils on four test sites were classified using computer-implemented pattern recognition techniques. Reference training samples were selected on the basis of a conventional soil survey map and were used to classify the remaining part of the test area. Mapping of soil features using multispectral scanner data was only partially successful because soil series are conventionally differentiated by both surface and subsurface properties. Further difficulty was encountered in attempting to map a soil series in one test area using training samples from another test area separated by only a few kilometers. These difficulties could have been due to differences in illumination at the two soil test areas, differences in surface roughness, surface texture, or surface color, adjustments in instrumentation during data collection, or other factors. A ratio of visible to infrared response appeared to have additional utility in characterizing the spectral properties of soils.

Kristof and Baumgardner (1975) used computer aided data processing techniques to separate Argiaquolls from Ochraqualfs in a corn field from seeding to maturity. Reflectivity measurements collected using an airborne multispectral scanner in the orange portion of the spectrum were used for grouping May and June data into seven different soil classes according to their spectral response. The computer produced spectral patterns had striking similarity to soil patterns on aerial photography. Soil patterns became less distinct as the season progressed due to masking of the crop canopy.

Hoffer et al. (1966), using airborne multispectral sensor data, revealed crop species and variety, relative maturity, percent canopy cover, and geometric configuration of the crop, often cause significant tonal variations in portions of the electromagnetic spectrum. September imagery was used in the study of crop identification and condition on a light colored highly reflective soil. At this date, corn was dry and had a spectral resonse similar to that of wheat stubble over the 400-900 nm wavelengths. Alfalfa (Medicago sativa) had a higher reflectance in the 700 to 900 nm region than corn, bare soil, or wheat stubble due to the high reflectance of most healthy green vegetation in this part of the spectrum. Alfalfa had a lower reflectance than bare soil, corn or wheat stubble in the visible portion of spectrum due to chlorophyll absorption. More of the soil reflectance signature was present in late planted corn than early planted corn due to a lower canopy density of the late planted corn. Although a dense vegetation may mask soil surface reflectance properties, differences among soils tend to influence the spectral signature of the crop canopy (Westin and Lemme, 1978).

The Soil Conservation Service utilizes high altitude panchromatic photography contracted by the United States Geological Survey as a base map for soil surveys (Miles Smalley, South Dakota State Soil Scientist, Soil Conservation Service, personal communication). The specifications require a film comparable to Kodak Plus-X Aerographic (2402) or Double-X Aerographic (2405) films (United States Geological Survey, Topographic Division, 1979). A minus-blue glass filter is used with panchromatic emulsions.

Panchromatic and color infrared photographs were taken in Spink County, South Dakota on six different dates during the 1970 growing season: May 14, June 25, July 21, August 12, September 10, November 5 (Frazee et al., 1972). The soil patterns were most clearly represented on the May photography. The field was planted to spring wheat which was 5-10 cm high. The light tones were severely eroded areas whereas the darkest tones were areas with wetness limitations. By the June 25 flight the wheat was full height and the surface soil pattern was almost completely masked. After harvest, the soil pattern was masked by standing wheat stubble.

Specht (1970) compared Kodak Infrared Aerographic film (2424) and panchromatic Plus-X (2402) photographs of scenes taken under clear versus hazy atmospheric conditions. Specht reported that under most atmospheric conditions, haze penetration was considerably greater using infrared film than panchromatic film because of less scatter of the infrared radiation than radiation of the visible part of the spectrum. The infrared film had a greater photographic range in each set of photographs than the panchromatic film especially under hazy conditions. Infrared film enhanced the contrast between distant objects, which contributes to the improvement in range. The contrast between water and growing vegetation was much greater on the infrared film than on the panchromatic film.

Multi band aerial photography using panchromatic film filtered with a Wratten 47B filter, a Wratten 61 filter, and a Wratten 72A filter was used to obtain the blue, green and red portions of the spectrum respectively (Evans, 1979). Contrast between a dark colored valley floor soil and a light colored chalky soil on aerial photos was greatest on the panchromatic photo filtered for the red portion of the spectrum. Tonal contrast was reduced as aerosol content increases. Photos taken at shorter wavelengths were more affected by scattering of light by aerosols than photos taken at longer wavelengths. Light is scattered proportionately and inversely to the fourth power of the wavelength. This Rayleigh-type scattering dominates at wavelengths shorter than 500 nm. Photos exposed in the blue waveband often have little tonal contrast.

Benson (1973) and Frazee et al. (1972) utilized 4 different film filter combinations to record the visible and near infrared portions of the spectrum. A four camera set up was used to allow comparisons that would determine the best spectral range for detecting soil limitations in Spink County, South Dakota. A comparison of the films indicated that the black and white (2402) film with the red (Wratten 25A) filter had the greatest contrast and the widest tonal range but the black and white (Kodak 2402) film with the green (Wratten 58) filter seemed to contain the middle range of densities making it more aesthetic to view. Of the black and white photographs tested, the soil patterns were always observed easiest on the panchromatic film filter for the red portion of the spectrum. The black and white infrared Kodak (2404) film using a deep red (Wratten 89B) filter did not contain more soil information than the other black and white films. The color infrared (Kodak 2443) film with Wratten G15 and 30M filters was easiest to view and contained the most soil information. Because the film is made up of three layers sensitive to green, red, and infrared radiation, the film can be filtered to yield each of the bands without regard for differences in processing and exposure.

The accuracy of panchromatic, infrared, color and color infrared photographs were evaluated in mapping soil and terrain features of forested mountain slopes and valleys in British Columbia, Canada

(Valentine et al., 1971). Soils were classified at the subgroup level of the Canadian soil classification system. Mapping units were delineated with an overall accuracy of 72 percent for the panchromatic, 78 percent for the color infrared, 79 percent for the black and white infrared, and 80 percent for Ektachrome color photography. Ektachrome color photography was most useful in delineating mapping units on the mountain slopes attaining an accuracy of 84 percent. In the valleys, the black and white infrared photographs were most useful attaining an accuracy of 80 percent. Contrasting moisture levels in the outwash and deltaic sand, marine clays, and alluvial silts were more apparent on the black and white infrared photography.

Frazee et. al. (1972) used panchromatic, infrared, and color infrared photography to determine their usefulness in making and updating soil and range inventories in an area dominated by rangeland. Kodak Plus-X Aerographic (2402) film with a Wratten 58 filter was used to obtain the green portion of the spectrum. Plus-X film with a Wratten 25A filter was used to obtain the red portion of the spectrum. Kodak Infrared Aerographic film with a Wratten 89B filter was used to obtain the near infrared portion of the spectrum. Kodak Aerochrome Infrared (2443) film with a Wratten 15G and CC30M filters was used to obtain the green, red, and near-infrared portions of the spectrum. June and August imagery were more useful than imagery obtained in October. General patterns of soils were displayed on the panchromatic and color infrared photography. The black and white infrared film had little contrast except for drainageways and depressions which had more actively growing vegetation. For rangeland soil mapping, the color infrared film correlated more closely to actual soil boundaries than the panchromatic or black and white infrared films.

MATERIALS AND METHODS

Data Collection

Panchromatic (500-700 nm), panchromatic (600-700 nm), and black and white infrared (700-900 nm) photography were collected on May 11, 1976 from an area of Turner County, South Dakota. A plane, equipped with three matched 70 mm Hasselblad cameras with a 15.24 cm focal length, was flown at an altitude of about 3033 meters. The cameras were mounted on a frame for simultaneous photography of the same area with each type of film. The photography was taken between 10:00 A. M. and 3:00 P. M. and consisted of six north-south flight lines across the county. Sixty percent overlap was allowed for stereoscopic coverage. The flight line lengths ranged from 32 frames to 43 frames. Prints at a scale of 1:20,000 were made from the negatives for field use.

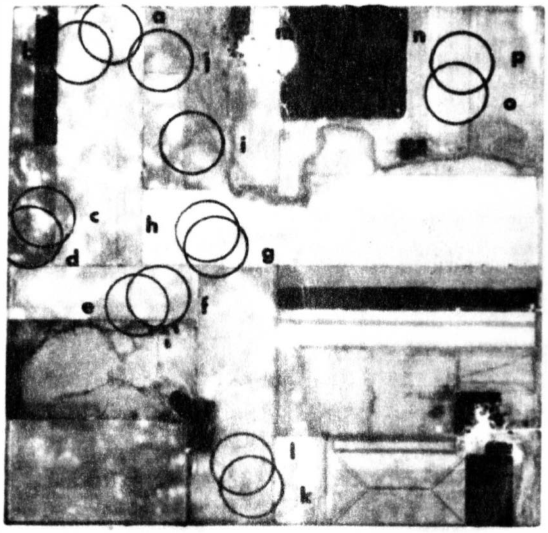
The panchromatic (600-700 nm) was obtained using Kodak Plus-X Aerographic (2402) film with a Wratten 25A filter to record dominately orange and red wavelengths (Eastman Kodak Company, 1970, Eastman Kodak Company, 1972a, and Eastman Kodak Company, 1972b). The panchromatic (500-700 nm) was obtained using Kodak Plus-X Aerographic (2402) film with Wratten HF3 and HF4 filters to record dominately the green, yellow, orange, and red part of the electromagnetic spectrum. Kodak Infrared Aerographic 2424 film with a Wratten 89B filter was used to represent only the near-infrared (700-900 nm) portion of the spectrum.

Transmission data from the film negatives was obtained using a Macbeth Spot Densitometer Model TD-404 with a resolution of 1 mm.

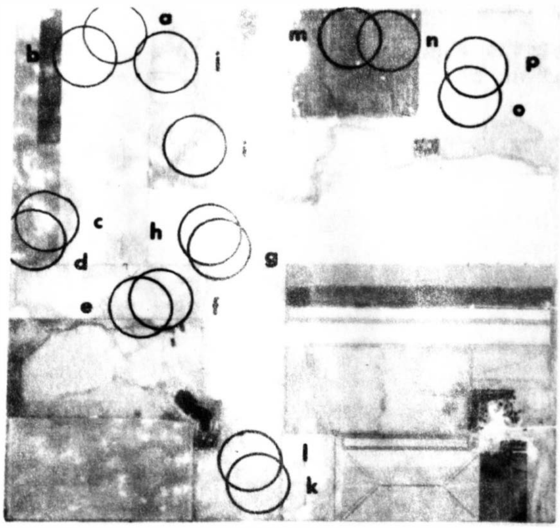
Through the use of the spot densitometer the gray tones on the film negatives in the selected test locations were converted to a relative digital format. Representative test locations were selected with an additional requirement that each test area have a uniform tone exceeding 1 mm in diameter. The points were marked on one set of prints to aid in finding the location on the negatives of each film type. An example of the data points on prints of each type of film is shown on Figure 3. The data point size equivalent to 1 mm on the negative would be about 2.5 mm in diameter on Figure 3. The site information for the same data point are recorded on Table 2. The correlated mapping unit and soil was recorded for each data point from the Turner County Soil Survey (Kunze, 1982). The soil series within the mapping unit was determined using photo interpretation procedures. The soil map from the Soil Survey of Turner County, South Dakota for the area on Figure 3 is shown on Figure 4. The surface cover was recorded for each data point utilizing crop history for 1975 and 1976 obtained from Agricultural Stabilization and Conservation Service, ground truth of the test area, and photo interpretation using the test imagery. All of the transmission measurements were made on one roll of film first than measurements were made of the same points of the other film types. Calibration of the densitometer was checked frequently.

The mapping unit, soil series, and land cover were coded and punched on computer cards along with the digital transmission values from the spot densitometer for each film type (Appendix A). The data

Figure 3. Example of data points on prints from the negatives that the transmission data was collected: (a) Panchromatic (600–700 nm), (b) Panchromatic (500–700 nm), and (c) Infrared (700–900 nm).

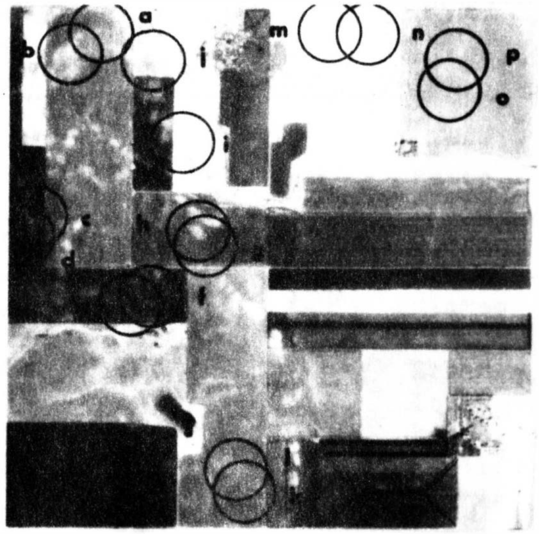


(a) Panchromatic (600–700 nm)



(b) Panchromatic (500–700 nm)

Figure 3. (continued)



(c) Infrared (700–900 nm)

Data points are located in the center of each circle. The letters reference the data points to point information on Table 2.

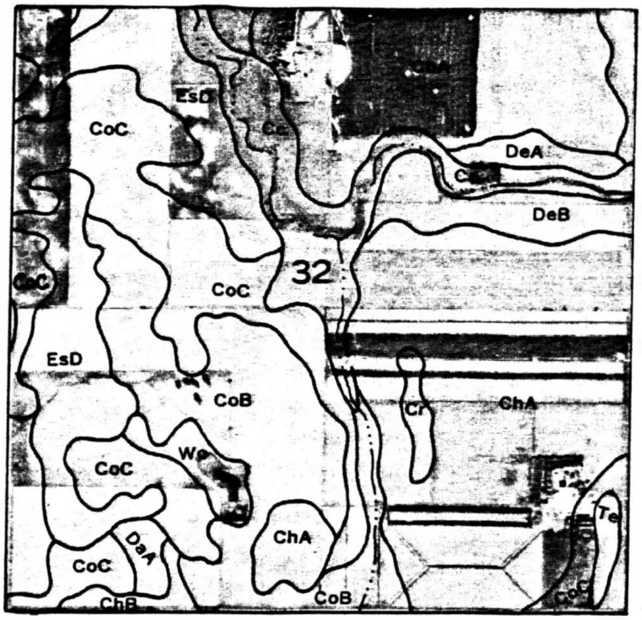
Table 2. Site information and transmission data collected for the data points on Section 32, Township 100 North, Range 53 West (Figure 3).

Data Point	Transmission Data Film† 1	2	3	Map Unit§	Soil	Land Cover
a	140	128	104	23	Ethan	Small Grain
b	155	139	107	23	Betts	Small Grain
c	129	120	70	14	Ethan	No Cover
d	110	102	60	14	Clarno	No Cover
e	133	122	77	14	Ethan	No Cover
f	127	121	81	14	Clarno	No Cover
g	141	129	92	14	Clarno	Crop Residue
h	155	142	105	14	Ethan	Crop Residue
i	118	115	132	23	Ethan	Pasture
j	127	120	115	23	Betts	Pasture
k	120	114	93	9	Bonilla	Small Grain
l	128	120	95	9	Clarno	Small Grain
m	93	100	140	9	Bonilla	Alfalfa
n	100	106	131	9	Clarno	Alfalfa
o	105	128	114	9	Clarno	Small Grain
p	131	125	115	9	Bonilla	Small Grain

†Film combination
1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

§Mapping Unit
9 Clarno-Bonilla loams, 0 to 2 percent slopes
14 Clarno-Ethan loams, 5 to 9 percent slopes
23 Ethan-Betts loams, 6 to 15 percent slopes

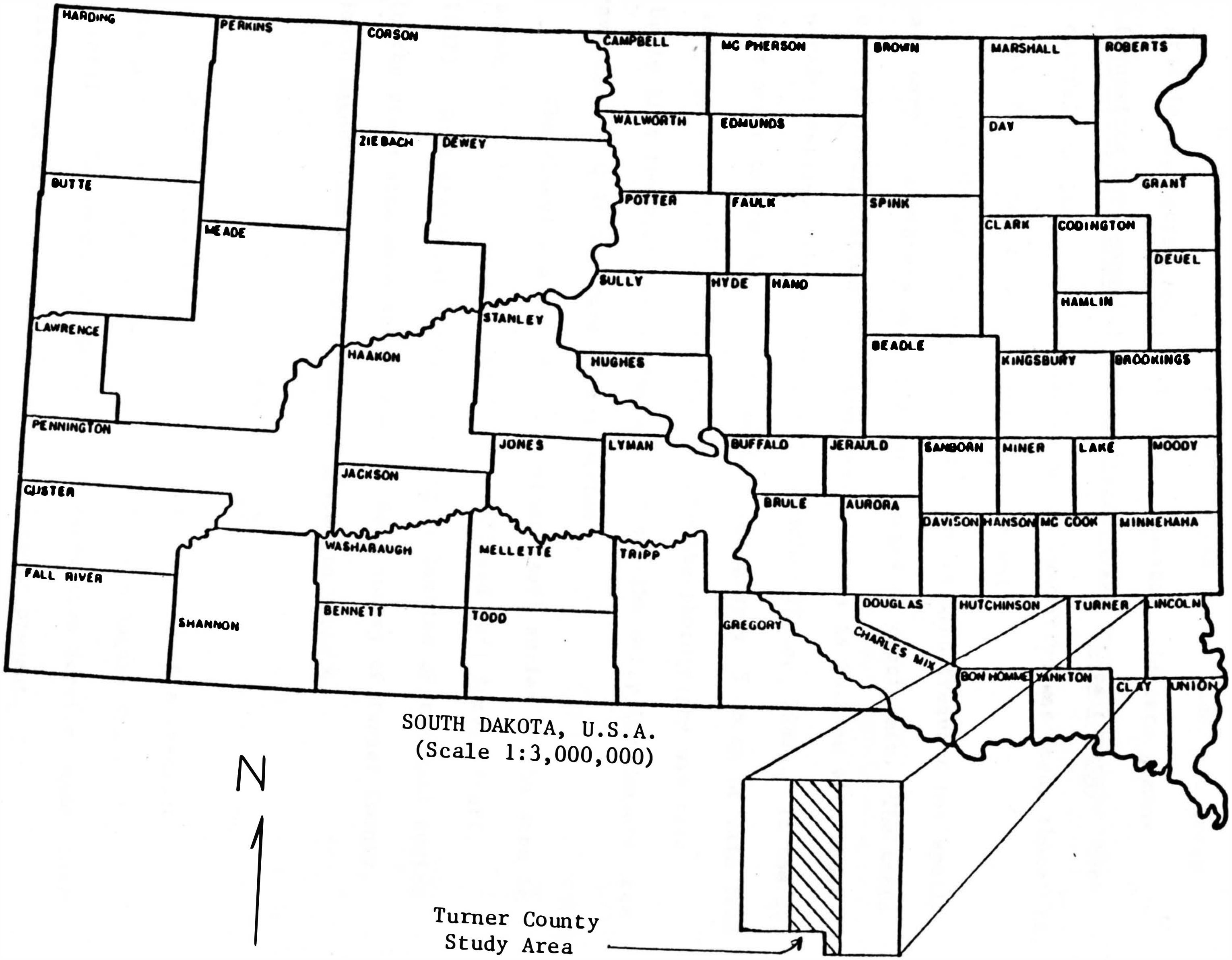
Figure 4. Soil map of Section 32, Township 100 North, Range 53 West (Kunze, 1982).



SOIL LEGEND

Cc	Chaska loam, channeled
ChA	Clarno-Bonilla loams, 0 to 2 percent slopes
ChB	Clarno-Bonilla loams, 1 to 6 percent slopes
CoB	Clarno-Ethan loams, 2 to 6 percent slopes
CoC	Clarno-Ethan loams, 5 to 9 percent slopes
Cr	Crossplain clay loam
DaA	Davis loam, 0 to 2 percent slopes
DeA	Delmont-Enet loams, 0 to 2 percent slopes
DeB	Delmont-Enet loams, 2 to 6 percent slopes
EsD	Ethan-Betts loams, 6 to 15 percent slopes
Te	Tetonka silt loam

Figure 5. Location of the Study Area



Soils on steeper slopes and knolls formed under mid grass prairie vegetation including little bluestem, sideoats gramma (Bouteloua curtipendula) and needleandthread (Stipa comata). Much rainfall is lost due to runoff. Range production was less; therefore, less organic matter was returned to the soil.

The climate consists of warm summers with frequent hot spells and very cold winters with frequent surges of arctic air. The total average precipitation at Marion, South Dakota is 60.2 cm with about 75 percent falling between April and September (Kunze, 1982). In the 30 days prior to the date of the aerial photography, 5.08 cm of rain fell although none fell in the 8 days before the photography was taken. Daily high temperatures averaged 17° C and the daily low temperatures averaged 3° C in the same 30 day period.

The classification of the dominant soil series of the area is shown in Table 3 (Soil Survey Staff, 1975 and Soil Survey Staff, 1982). Soil characteristics affecting reflection of the soil series in the study area were taken from the Soil Survey of Turner County, South Dakota (Kunze, 1982) and are listed in Table 4.

Ground Truth

Ground truth was collected on May 14, 1976 of a transect through the study area. Fred C. Westin, South Dakota State University, and Dennis M. Heil, Soil Conservation Service, made observation of amount and condition of ground cover present.

At the time that photography was collected, many fields had no land cover in preparation for planting of corn and soybeans. Some

Table 3. Classification of the major soils in the study area (Soil Survey Staff, 1982).

Soil	Classification
Betts	fine-loamy, mixed (calcareous), mesic, Typic Ustorthents
Bonilla	fine-loamy, mixed, mesic, Pachic Haplustolls
Clarno	fine-loamy, mixed, mesic, Typic Haplustolls
Crossplain	fine, montmorillonitic, mesic Typic Argiaquolls
Davison	fine-loamy, mixed, mesic, Aquic Calciustolls
Ethan	fine-loamy, mixed, mesic, Typic Calciustolls
Tetonka	fine, montmorillonitic, mesic, Argiaquic Argialbolls
Worthing	fine, montmorillonitic, mesic, Typic Argiaquolls

Table 4. Soil characteristics affecting spectral reflectance (Kunze, 1982).

Soil Series	Dominant Munsell Colors		Organic Matter %	Drainage Class	Landscape Position	Soil Texture
	Dry	Moist				
Betts	10YR 4/2	10YR 2/2	1 - 3	Well	Shoulder	Loam
Bonilla	10YR 3/1	10YR 2/1	4 - 6	Moderately well	Footslope	Loam
Clarno	10YR 3/1	10YR 2/1	2 - 4	Well	Backslope	Loam
Crossplain	10YR 4/1	10YR 2/1	3 - 6	Somewhat poorly	Footslope	Clay loam
Davison	10YR 4/2	10YR 3/2	2 - 4	Moderately well	Backslope	Loam
Ethan	10YR 4/2	10YR 3/2	1 - 3	Well	Shoulder	Loam
Tetonka	10YR 4/1	10YR 2/1	4 - 8	Poorly	Toeslope	Silt loam
Worthing	10YR 3/1	10YR 2/1	4 - 8	Very poorly	Toeslope	Silty clay loam

fields were plowed in the fall while other fields were spring plowed or spring disked. The amount of crop residue on the surface was generally small. Moisture content of the surface varied due to the time of the last tillage as well as the soil characteristics.

Some fields were covered by crop residue from the previous crop year. The residue consisted mostly of corn, soybean, or small grain residue. Some fields covered with soybean residue were included with the fields with no land cover because the amount of residue was small.

The alfalfa crop was growing vigorously on the day the photography was flown. The alfalfa ranged from 15 to 20 cm in height.

Pastures in the study area are dominantly introduced species of cool season grasses and warm season native grasses. The cool season grasses generally were 5 to 13 cm tall. The cool season grass component of the native pastures were beginning to grow and were 2 to 8 cm tall. The warm season species were generally dormant. Some pastures were being grazed.

Other areas were planted to small grains. The major small grains grown in the area are oats, wheat, and barley (*Hordeum vulgare*). The seedbed preparation generally consisted of disking or plowing and disking. The amount of crop residue on the surface varied depending on the previous crop and the method of seedbed preparation. At the time of aerial photography most small grain was 5 to 8 cm tall.

On nearly level landscapes, many areas of cropland were fall plowed. The main crop rotation in the area is corn-soybeans. Many farms in the area have small fields of alfalfa.

On undulating landscapes, more residue was left on the surface due to less fall tillage to control soil erosion. Crop rotations have more close grown crops such as pasture, alfalfa, and small grain than the nearly level landscapes.

Most areas of Betts soil tended to be in close grown crops of pasture and small grain due to slope. Worthing and Tetonka soils tended to be fall tilled in areas planted to crops. These soils dry slowly due to their depressional setting and are planted late to corn and soybeans. Alfalfa will not survive in undrained areas of Tetonka and Worthing soils due to wetness.

Data Analysis

Statistics of mean, standard deviation, standard error, minimum value, maximum value, and coefficient of variability for each film by cover and soil were calculated (Appendix B). Discriminate analysis was used to analyse data with one classification variable and several continuous variables (Statistical Analysis Systems, 1982). The purpose of discriminate analysis is to find a subset of variables that best reveals differences among the classes, or to find a rule for placing observations into the classes from knowledge of the continuous variables. In this thesis, two discriminate analysis subroutines were utilized.

STEPDISC Subroutine

The STEPDISC subroutine was utilized to try to find a subset of variables that best reveals differences among the soil classes. The data for each landscape (nearly level and undulating) and each mapping unit complex was stratified as to land cover because of the different spectral properties associated with each land cover type. Complexes consist of two or more dissimilar taxa components or miscellaneous areas occuring in a regularly repeating pattern. Discriminate analysis was performed on each soil cover grouping using transmission data from the three film types. The STEPDISC procedure is most appropriate for approximately normally distributed data.

The STEPDISC procedure performs a stepwise discriminant analysis by forward and backward selection to select a subset of quantitative variables that produce a good discrimination model. The groups are assumed to be multivariable normal with a common covariance matrix.

Film variables were chosen to enter or leave according to the significance level of an F test from an analysis of covariance, where the film variable(s) already chosen act as covariates and the film variable under consideration is the dependent variable.
If a model is desired that provides the best discrimination using the sample estimate, the data analyst need ony guard against estimating more parameters than can be reliably estimated with a given sample size. In this case, a significance level of 0.15 was used for entry into the model and 0.05 to stay in the model. Increasing the sample size tends to increase the number of variables selected.

Stepwise selection begins with no film variables in the discriminant model. At each step, if a film variable already entered at the 0.15 significance level fails to meet the 0.05 significance level to stay, the film variable is removed. Then the film variable that contributes most to the discriminatory power of the model (as measured by Wilks' lambda) is entered. When all variables in the model meet the 0.05 significane level to stay and none of the other film variables meet the 0.05 significance level to enter, the stepwise selection process stops. An example of the STEPDISC procedure is in Appendix C.

DISCRIM Subroutine

After selection of a subset of variables with STEPDISC, the DISCRIM subroutine was used to obtain more detailed analysis. The DISCRIM subroutine was used to evaluate the subset of film variables that best revealed the difference among the soil classes from the STEPDISC subroutine. The DISCRIM procedure computes linear or quadratic discriminant functions for classifying observations into two or more soil groups on the basis of one or more numeric film variables. DISCRIM develops a discriminant model to classify each observation into one of the soil groups. Each observation is placed in the soil group from which it has the smallest generalized squared distance. The distribution within each group should be approximately multivariate normal. The discriminant model is determined by generalized squared distance. The discriminant model can be based on either individual within-group covariance matrices or the pooled covariance matrix taking into account the proportional prior probabilities of the soil groups. DISCRIM tests the homogeneity of the within-group covariance matrices. The results of the test determine whether the discriminant model is based on the within-group covariance matrices or the pooled covariance matrix. An example of the DISCRIM procedure is in Appendix

D. The posterior classification of the soils within each soil/cover group for the film variables selected using the STPEDISC subroutine is shown in Appendix E.

RESULTS AND DISCUSSION

Stepwise Discriminant Analysis Within Each Soil Grouping with No Land Cover

Stepwise discriminant analysis was attempted on each soil grouping stratified as to land cover to try to find a subset of films that best reveals differences among the soils (Table 5). The panchromatic (600-700 nm) (1) film revealed the greatest difference among the soils in areas with no land cover using a single film within each soil grouping with the exception of soils within the Clarno-Crossplain-Davison complex. With one exception, the difference among soil transmission means within a single film was greatest using the panchromatic (600-700 nm) film on groupings with no land cover (Tables 6, 7, 8, 9 and 10). The means of the Clarno, Crossplain, and Davison soils within the Clarno-Crossplain-Davison complex were a greater distance apart using the panchromatic (600-700 nm) film than the panchromatic (500-700 nm) film. However, the total sample standard deviation was 10.4 for the panchromatic (600-700 nm) film compared to 6.2 for the panchromatic (500-700 nm) film resulting in a higher initial entry r^2 value for the panchromatic (500-700 nm) (2) film (Table 5). The greater distance between transmission means of the panchromatic (600-700 nm) than the panchromatic (500-700 nm) film is agreement with the findings of Obukov and Orlov (1964), who found that in the visible spectrum the greatest difference among unvegetated soils is observed in the red portion of the spectrum, making it most useful for discriminating among soils using soil reflectance data. Reflection dif-

Table 5. Film variables entered and coefficients of determination using stepwise discriminant analysis of soils within soil groupings by land cover.†

Land Cover	Undulating Landscapes	Nearly Level Landscapes	Clarno-Bonilla Complex	Clarno-Ethan Complex	Clarno-Crossplain Davison Complex
No Cover	1,2,3 (111)#§ r^2 = .50**	1,2 (115) r^2 = .29**	1 (78) r^2 = .10**	1 (64) r^2 = .30**	2 (24) r^2 = .48**
Crop Residue	1,3 (36) r^2 = .51**	---	1 (34) r^2 = .14*	1,3 (17) r^2 = .48**	---
Alfalfa	2 (33) r^2 = .24**	1 (43) r^2 = .25**	ns (20)	2 (26) r^2 = .18*	1 (25) r^2 = .54**
Pasture	3 (48) r^2 = .27**	---	---	ns (18)	---
Small Grain	1 (86) r^2 = .33**	---	ns (62)	1 (42) r^2 = .23**	---

--- Not evaluated

†Film variables were entered in the order listed.

§Numbers in parenthesis refer to the total number of observations within the grouping.

\# Films

1 Panchromatic (600-700 nm)

2 Panchromatic (500-700 nm)

3 Infrared (700-900 nm)

ns = Not significant at 0.05 level.
* = Significant at 0.05 level.
** = Significant at 0.01 level.

Table 6. Number of observations, mean, and standard deviation of film transmission data by cover and soil on undulating landscapes.

Film	No. of Observations	Transmission Mean	Standard Deviation
No Cover--Bonilla			
Panchromatic (600-700 nm)	12	113.0	7.6
Panchromatic (500-700 nm)	12	102.2	7.6
Infrared (700-900 nm)	12	72.5	10.4
No Cover--Clarno			
Panchromatic (600-700 nm)	41	116.2	10.5
Panchromatic (500-700 nm)	41	105.0	9.7
Infrared (700-900 nm)	41	79.5	12.9
No Cover--Ethan			
Panchromatic (600-700 nm)	47	130.2	14.2
Panchromatic (500-700 nm)	47	116.9	12.3
Infrared (700-900 nm)	47	87.0	11.7
No Cover--Worthing			
Panchromatic (600-700 nm)	11	101.6	9.7
Panchromatic (500-700 nm)	11	99.6	10.1
Infrared (700-900 nm)	11	66.2	12.1
Crop Residue--Bonilla			
Panchromatic (600-700 nm)	9	131.9	6.0
Panchromatic (500-700 nm)	9	117.8	5.9
Infrared (700-900 nm)	9	88.7	8.1
Crop Residue--Clarno			
Panchromatic (600-700 nm)	17	134.1	9.8
Panchromatic (500-700 nm)	17	119.2	8.9
Infrared (700-900 nm)	17	88.5	10.4
Crop Residue--Ethan			
Panchromatic (600-700 nm)	10	148.9	14.7
Panchromatic (500-700 nm)	10	130.4	13.0
Infrared (700-900 nm)	10	98.7	14.1
Alfalfa--Clarno			
Panchromatic (600-700 nm)	13	83.6	14.5
Panchromatic (500-700 nm)	13	87.2	8.9
Infrared (700-900 nm)	13	124.5	17.5
Alfalfa--Ethan			
Panchromatic (600-700 nm)	20	97.1	14.8
Panchromatic (500-700 nm)	20	98.3	10.4
Infrared (700-900 nm)	20	125.4	17.3
Pasture--Clarno			
Panchromatic (600-700 nm)	9	109.7	6.7
Panchromatic (500-700 nm)	9	102.8	6.2
Infrared (700-900 nm)	9	114.2	17.8
Pasture--Ethan			
Panchromatic (600-700 nm)	17	115.2	9.6
Panchromatic (500-700 nm)	17	108.3	7.4
Infrared (700-900 nm)	17	119.2	10.6

Table 6 — continued.

Film	No. of Observations	Transmission Mean	Standard Deviation
Pasture--Worthing			
Panchromatic (600-700 nm)	12	112.0	19.8
Panchromatic (500-700 nm)	12	106.5	16.2
Infrared (700-900 nm)	12	98.8	17.4
Pasture--Betts			
Panchromatic (600-700 nm)	10	117.7	11.3
Panchromatic (500-700 nm)	10	110.7	9.9
Infrared (700-900 nm)	10	117.4	11.0
Small Grain--Bonilla			
Panchromatic (600-700 nm)	13	114.2	12.1
Panchromatic (500-700 nm)	13	109.2	8.9
Infrared (700-900 nm)	13	106.1	8.1
Small Grain--Clarno			
Panchromatic (600-700 nm)	31	116.9	12.2
Panchromatic (500-700 nm)	31	110.2	9.6
Infrared (700-900 nm)	31	103.6	10.2
Small Grain--Ethan			
Panchromatic (600-700 nm)	38	129.2	11.5
Panchromatic (500-700 nm)	38	117.6	10.1
Infrared (700-900 nm)	38	105.2	8.9
Small Grain--Betts			
Panchromatic (600-700 nm)	4	145.0	9.1
Panchromatic (500-700 nm)	4	127.3	8.8
Infrared (700-900 nm)	4	112.0	4.4

Table 7. Number of observations, mean, and standard deviation of film transmission data by cover and soil on nearly level landscapes.

Film	No. of Observations	Transmission Mean	Standard Deviation
No Cover--Bonilla			
Panchromatic (600-700 nm)	27	110.9	8.1
Panchromatic (500-700 nm)	27	103.1	7.3
Infrared (700-900 nm)	27	71.4	8.3
No Cover--Clarno			
Panchromatic (600-700 nm)	35	114.6	8.4
Panchromatic (500-700 nm)	35	105.3	6.8
Infrared (700-900 nm)	35	73.9	8.3
No Cover--Crossplain			
Panchromatic (600-700 nm)	13	107.0	9.1
Panchromatic (500-700 nm)	13	99.8	6.7
Infrared (700-900 nm)	13	69.5	12.8
No Cover--Davison			
Panchromatic (600-700 nm)	8	119.5	9.5
Panchromatic (500-700 nm)	8	108.9	5.1
Infrared (700-900 nm)	8	78.1	5.5
No Cover--Tetonka			
Panchromatic (600-700 nm)	21	110.5	12.3
Panchromatic (500-700 nm)	21	104.1	11.3
Infrared (700-900 nm)	21	70.1	13.1
No Cover--Worthing			
Panchromatic (600-700 nm)	11	101.6	9.7
Panchromatic (500-700 nm)	11	99.6	10.1
Infrared (700-900 nm)	11	66.2	12.1
Alfalfa--Bonilla			
Panchromatic (600-700 nm)	9	70.0	14.2
Panchromatic (500-700 nm)	9	85.3	12.3
Infrared (700-900 nm)	9	138.1	16.1
Alfalfa--Clarno			
Panchromatic (600-700 nm)	16	76.9	9.9
Panchromatic (500-700 nm)	16	88.7	9.3
Infrared (700-900 nm)	16	130.7	10.6
Alfalfa--Crossplain			
Panchromatic (600-700 nm)	8	69.8	3.5
Panchromatic (500-700 nm)	8	83.3	1.6
Infrared (700-900 nm)	8	138.6	10.0
Alfalfa--Davison			
Panchromatic (600-700 nm)	10	84.0	8.3
Panchromatic (500-700 nm)	10	90.4	5.0
Infrared (700-900 nm)	10	128.6	6.4

Table 8. Number of observations, mean, and standard deviation of film transmission data by cover and soil of Clarno and Bonilla soils on nearly level and undulating landscapes.

Film	No. of Observations	Transmission Mean	Standard Deviation
---No Cover--Clarno---			
Panchromatic (600-700 nm)	39	116.7	8.0
Panchromatic (500-700 nm)	39	106.1	7.0
Infrared (700-900 nm)	39	75.6	10.5
---No Cover--Bonilla---			
Panchromatic (600-700 nm)	39	111.5	7.9
Panchromatic (500-700 nm)	39	102.8	7.3
Infrared (700-900 nm)	39	71.8	8.9
---Crop Residue--Clarno---			
Panchromatic (600-700 nm)	17	134.9	7.2
Panchromatic (500-700 nm)	17	121.1	5.3
Infrared (700-900 nm)	17	89.9	7.7
---Crop Residue--Bonilla---			
Panchromatic (600-700 nm)	17	129.0	8.3
Panchromatic (500-700 nm)	17	117.1	5.4
Infrared (700-900 nm)	17	87.3	7.5
---Alfalfa--Clarno---			
Panchromatic (600-700 nm)	10	76.4	12.5
Panchromatic (500-700 nm)	10	89.9	11.8
Infrared (700-900 nm)	10	131.3	12.1
---Alfalfa--Bonilla---			
Panchromatic (600-700 nm)	10	70.2	13.4
Panchromatic (500-700 nm)	10	84.8	11.7
Infrared (700-900 nm)	10	139.2	15.6
---Small Grain--Clarno---			
Panchromatic (600-700 nm)	30	121.0	11.3
Panchromatic (500-700 nm)	30	114.4	9.3
Infrared (700-900 nm)	30	107.1	10.3
---Small Grain--Bonilla---			
Panchromatic (600-700 nm)	32	115.7	12.4
Panchromatic (500-700 nm)	32	111.1	8.6
Infrared (700-900 nm)	32	105.1	9.3

Table 9. Number of observations, mean, and standard deviation of film transmission data by cover and soil of Clarno and Ethan soils on undulating landscapes.

Film	No. of Observations	Transmission Mean	Standard Deviation
---No Cover--Clarno---			
Panchromatic (600-700 nm)	29	115.3	11.5
Panchromatic (500-700 nm)	29	104.8	10.7
Infrared (700-900 nm)	29	80.3	12.7
---No Cover--Ethan---			
Panchromatic (600-700 nm)	35	132.6	14.5
Panchromatic (500-700 nm)	35	118.9	12.9
Infrared (700-900 nm)	35	89.3	11.9
---Crop Residue--Clarno---			
Panchromatic (600-700 nm)	8	130.4	12.1
Panchromatic (500-700 nm)	8	116.4	11.3
Infrared (700-900 nm)	8	84.8	11.8
---Crop Residue--Ethan---			
Panchromatic (600-700 nm)	9	147.6	14.9
Panchromatic (500-700 nm)	9	129.7	13.5
Infrared (700-900 nm)	9	97.4	14.4
---Alfalfa--Clarno---			
Panchromatic (600-700 nm)	12	84.3	14.9
Panchromatic (500-700 nm)	12	87.3	9.3
Infrared (700-900 nm)	12	123.3	17.7
---Alfalfa--Ethan---			
Panchromatic (600-700 nm)	14	96.9	16.9
Panchromatic (500-700 nm)	14	97.3	12.1
Infrared (700-900 nm)	14	125.9	20.9
---Pasture--Clarno---			
Panchromatic (600-700 nm)	7	108.3	9.4
Panchromatic (500-700 nm)	7	102.1	6.6
Infrared (700-900 nm)	7	119.9	10.0
---Pasture--Ethan---			
Panchromatic (600-700 nm)	11	114.1	11.0
Panchromatic (500-700 nm)	11	106.7	8.0
Infrared (700-900 nm)	11	116.0	7.4
---Small Grain--Clarno---			
Panchromatic (600-700 nm)	18	115.4	12.1
Panchromatic (500-700 nm)	18	108.5	8.3
Infrared (700-900 nm)	18	100.1	10.5
---Small Grain--Ethan---			
Panchromatic (600-700 nm)	24	128.0	11.1
Panchromatic (500-700 nm)	24	118.3	9.4
Infrared (700-900 nm)	24	106.4	9.5

Table 10. Number of observations, mean, and standard deviation of film transmission data by cover and soil of Clarno, Crossplain and Davison soils on nearly level landscapes.

Film	No. of Observations	Transmission Mean	Standard Deviation
No Cover--Clarno			
Panchromatic (600-700 nm)	8	110.1	7.5
Panchromatic (500-700 nm)	8	101.9	3.3
Infrared (700-900 nm)	8	70.9	5.5
No Cover--Crossplain			
Panchromatic (600-700 nm)	8	105.9	10.0
Panchromatic (500-700 nm)	8	98.9	5.2
Infrared (700-900 nm)	8	68.5	4.8
No Cover--Davison			
Panchromatic (600-700 nm)	8	119.5	9.5
Panchromatic (500-700 nm)	8	108.9	5.1
Infrared (700-900 nm)	8	78.1	5.5
Alfalfa--Clarno			
Panchromatic (600-700 nm)	7	77.6	3.6
Panchromatic (500-700 nm)	7	86.6	1.4
Infrared (700-900 nm)	7	131.1	8.8
Alfalfa--Crossplain			
Panchromatic (600-700 nm)	8	69.8	3.5
Panchromatic (500-700 nm)	8	83.3	1.6
Infrared (700-900 nm)	8	138.6	10.0
Alfalfa--Davison			
Panchromatic (600-700 nm)	10	84.0	8.3
Panchromatic (500-700 nm)	10	90.4	5.0
Infrared (700-900 nm)	10	128.6	6.4

ferences between reflectance curves (a) and (b) of Stoner and Baumgardner (1981) shows greater differences in the near infrared region than the visible region of the spectrum; however the infrared (700-900 nm) film has lower transmission values on unvegetated soils than the two panchromatic films due to differences in film sensitivity.

The coefficient of determination was highest for soils within undulating landscapes and lowest for soils within the Clarno-Bonilla complex. The higher r^2 value of the soils within the undulating landscape with no land cover is due in part to the differences in drainage class and organic matter content (Table 4). Many areas of the Ethan soils are moderately eroded with calcareous Bk horizon material mixed with the Ap horizon material. Eroded soils have higher reflectance than adjoining non-eroded soils as was noted by Frazee et al. (1972), Latz et al. (1981), and Westin (1975). The calcium carbonate in the surface layer of the Ethan soil also increases reflectance (Hovis, 1966).

The lower r^2 of the Clarno and Bonilla soils within the Clarno-Bonilla complex is due partially to the greater similarity of the soils (Table 5).

Discriminant Classification of Soils With No Land Cover

The order of decrease in surface organic matter content of the soils are: Worthing = Tetonka > Crossplain = Bonilla > Clarno = Davison $\geq$ Ethan (Table 4). The order of decreasing surface moisture contents of the soils probably would have been: Worthing $\geq$

Tetonka > Crossplain > Bonilla = Davison $\geq$ Clarno > Ethan due to landscape position and water-holding capacity as a result of decreasing clay and organic matter content. Surface textures range from silty clay loam to loam. The dominant moist Munsell color of the surface soils is dominantly 10YR 2/1 for the Bonilla, Clarno, Crossplain, Tetonka and Worthing soils; and 10YR 3/2 for the Ethan and Davison soils.

The soils found in the study area would most likely fit the following spectral curves as defined by Stoner and Baumgardner (1981): Crossplain, Tetonka, and Worthing soil as curve (a), Bonilla soil as curve (a) or (b), the Clarno and Davison soils as curve (b), and the Ethan soil as curve (b) or (c) (Figure 1).

Undulating Landscapes

Clarno and Ethan soils tended to be distinguished more often than other soils on undulating landscapes with no land cover using the panchromatic (600-700 nm) (1) film with an overall accuracy of 59 percent (Table 11). Most of the incorrectly classified observations of the Clarno soil were classified as Ethan soil and vice versa (Appendix C, Table 1a). The lower percent correct classification of the Worthing soil is due to overlap caused the variability within each soil class, and the lower prior probability of the Worthing soil than the Clarno soil. All of the misclassified Worthing data points were classified as Clarno soil due to the overlap of data points as well as the higher priority probability for the Clarno soil. The Bonilla soil was never classified correctly on undulating landscapes using only the

Table 11. Percent soils classified correctly by soil grouping with no land cover.†

Soil	Film§					
	1	2	3	1,2	1,3	1,2,3
----------Undulating Landscapes----------						
Bonilla (12)	0			0		25
Clarno (41)	71			68		62
Ethan (47)	68			68		70
Worthing (11)	36			100		100
Over-all (111)	59			64		65
----------Nearly Level Landscapes----------						
Bonilla (27)	19			33		
Clarno (35)	89			66		
Crossplain (13)	0			8		
Davison (8)	0			25		
Tetonka (21)	0			29		
Worthing (11)	36			82		
Over-all (115)	31			43		
----------Clarno-Bonilla Complex----------						
Clarno (39)	67					
Bonilla (39)	72					
Over-all (78)	69					
----------Clarno-Ethan Complex----------						
Clarno (29)	72					
Ethan (35)	74					
Over-all (64)	73					
----------Clarno-Crossplain-Davison Complex----------						
Clarno (8)		37				
Crossplain (8)		50				
Davison (8)		75				
Over-all (24)		50				

†Number in parenthesis refers to the number of observations for that soil.

§Film combinations

1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

panchromatic (600–700 nm) (1) film (Table 11). The Clarno and Ethan soils may have a closely related spectral curve (Stoner and Baumgardner, 1981). Both soils typically have a moist Munsell color of 10YR 2/1 (Table 4). A majority of the Bonilla data points were classified as Clarno soil due to the overlap of transmission data caused by similarity of soil moisture, texture, and organic matter content between the Bonilla and Clarno soils.

Combinations of the panchromatic (600–700 nm) (1) and the panchromatic (500–700 nm) (2) films were useful in increasing the over-all accuracy of soil detection to 64 percent (Table 11). The improvement in correct classification is due to a reduction of confusion among the soil classes (Appendix C, Table 1b). A combination of all three films increased the over-all percent of the soils on undulating landscapes classified correctly to 65 percent (Table 11). Although no data points of the Bonilla soil were classified correctly using only one film, the percentage classified correctly was increased to 25 percent by using a combination of all three films. The improvement in classification of the Bonilla soil may be due to the differences in the reflectance properties of soils at the wavelengths recorded on the three types of films. The increase in the accuracy by using a combination of wavelengths in classifying soil groups is documented by several authors (Kristof and Zachary, 1974; Kristof and Baumgardner, 1975; Lewis et al., 1975; Westin and Myers, 1973; Westin and Frazee, 1976; and Westin and Lemme, 1978).

Nearly Level Landscapes

The Clarno soil tended to be distinguished more often than the other soils on nearly level landscapes with no land cover using a single film with panchromatic (600-700 nm) (1) film resulting in an over-all accuracy of 31 percent. No data points of Crossplain, Davison, or Tetonka were classified correctly. The high percent of the Clarno soils classified correctly using each of the films singly may be artificial in that a majority of the misclassified data points were classified as Clarno soil, due to the large amount of overlap among soil groups as well as to the greater prior probability of membership in the Clarno soil than the other soils (Appendix C, Table 2a).

The percent over-all classification of the soils on nearly level landscapes was low mainly due to the similarities among the soils within the landscape. All of the soils except the Davison soil have a moist Munsell color of 10YR 2/1 (Table 4). The organic matter content and landscape position of the following soils is similar: Tetonka and Worthing, Bonilla and Crossplain, and Clarno and Davison. Surface texture ranges from loam to silty clay loam. Also the percent correct classification is reduced by attempting to classify a large number of soils.

More soils on nearly level landscapes with no land cover were discriminated by using a combination of the panchromatic (600-700 nm) (1) and panchromatic (500-700 nm) (2) films (Table 11). Only three of the six soils were discriminated using a single film; however, all six soils were discriminated using a combination of the panchromatic

(600-700 nm) (1) and the panchromatic (500-600 nm) (2) films obtaining an over-all correct classification of 43 percent. The discrimination of more soils may be a result of differences in the spectral regions represented by each film type. Although the Crossplain and Davison soils were never classified correctly using the panchromatic (600-700 nm) (1) or the (500-700 nm) (2) films singly, the percent classified correctly increased to 8 and 25 percent respectively using a combination of the panchromatic (600-700 nm) (1) and panchromatic (500-700 nm) (2) films. The increase in percent correct classification of these soils is due to improved separation among the soils by using measurements from a combination of films. The percent of the Clarno soil classified correctly decreased by using a combination of films. This may be due to increasing the area of correct classification of the other soils and overlap among the soils.

Over-all percent of the soils classified correctly on nearly level landscapes was lower than that on undulating landscapes, due to more similarity among soils within the nearly level landscapes than the undulating landscapes as well as the greater number of soil classes compared on the nearly level landscapes.

Clarno and Bonilla Soils Within the Clarno-Bonilla Complex

The panchromatic (600-700 nm) (1) film was the most useful film for discriminating the Clarno and Bonilla soils within the Clarno-Bonilla complex on nearly level and undulating landscapes with no land cover. Sixty-seven percent of the Clarno soil and

72 percent of the Bonilla soil was classified correctly resulting in an over-all accuracy of 69 percent. Even though the Clarno and Bonilla soils are fairly similar, the over-all accuracy in classifying the soils within the Clarno-Bonilla complex was higher than the over-all accuracy of classifying soils within undulating landscapes or nearly level landscapes. The greater over-all accuracy is due domonantly to the fewer soil classes being compared within the Clarno-Bonilla complex than within undulating landscapes or nearly level landscapes. Four soil classes were compared on undulating landscapes and six classes were compared on nearly level landscapes.

Clarno and Ethan Soils Within the Clarno-Ethan Complex

The panchromatic (600-700 nm) (1) film was the most useful film for discriminating the Clarno and Ethan soils within the Clarno-Ethan complex with no land cover. Seventy-two percent of the Clarno soil and 74 percent of the Ethan soil was classified correctly resulting in an over-all accuracy of 73 percent. The over-all accuracy of discriminating soils was higher for the soils within the Clarno-Ethan complex than for any other soil grouping with no land cover. The over-all accuracy of discriminating soils within the Clarno-Ethan complex is higher than that within the Clarno-Bonilla complex due to the greater differences in surface characteristics of the Clarno and Ethan soils than the Clarno and Bonilla soils, mainly due to differences in organic matter and moisture content and to the presence of calcium carbonate in the surface of the Ethan soil. The over-all accuracy of discriminating soils was higher for the soils within the

Clarno-Ethan complex than within the undulating and nearly level landscapes and the Clarno-Crossplain-Davison complex. This is due in part to the fewer soil classes compared.

Clarno, Crossplain, and Davison Within the Clarno-Crossplain-Davison Complex

The panchromatic (500-700 nm) (2) film was the most useful film for discriminating the Clarno, Crossplain, and Davison soils within the Clarno-Crossplain-Davison complex. Percent accuracy was 37, 50 and 75 for the Clarno, Crossplain, and Davison soils respectively resulting in an over-all accuracy of 50 percent. There was much overlap in the data between the Crossplain and Clarno soils and the Clarno and Davison soils due to similar moisture and organic matter content (Appendix C, Table 5).

The over-all accuracy in discriminating the soils within the Clarno-Crossplain-Davison complex with no land cover was higher than that of discriminating soils on nearly level landscapes (Table 11). The increase in accuracy is mainly a result of reducing the number of soil classes compared from six to three.

Stepwise Discriminant Analysis Within Each Soil Grouping Covered with Crop Residue

The panchromatic (600-700 nm) (1) film revealed the greatest differences among soils in areas covered with crop residue using a single film (Table 5). The r^2 was increased using a combination of the panchromatic (600-700 nm) (1) and the infrared (700-900 nm) (3) films within undulating landscapes and the Clarno-Ethan complex. The reflectance of the residue covered soils in the near infrared portion of the spectrum further separated the soil groups containing the Ethan soil. The increased separation may be due to greater difference in mean transmission values between the panchromatic (600-700 nm) film and the infrared (700-900 nm) film for the Ethan soil than the Clarno or Bonilla soils (Tables 6, 8 and 9). Ethan soils tend to crust easier than Clarno or Bonilla soils resulting in increased reflectance for the Ethan soil.

The coefficient of determination was highest within undulating landscapes and within the Clarno-Ethan complex and lowest within the Clarno-Bonilla complex (Table 5). This is due partially to the greater background reflectance difference between the Clarno and Ethan soils than the Clarno and Bonilla soils.

Discriminant Classification of Soils Covered with Crop Residue

Undulating Landscapes

The panchromatic (600-700 nm) (1) film was the most useful single film for discriminating soils on undulating landscapes covered with crop residue; however, the Clarno and Ethan soils were the only soils discriminated (Table 12). There was no discrimination of the Bonilla soil from the Clarno and Ethan soils. This is due to the similar characteristics of the surface of the Clarno and Bonilla soils as well as the similarity in residue cover. More of the Clarno and Ethan soils were classified correctly due to greater differences in surface

Table 12. Percent soils classified correctly by soil grouping covered with crop residue.†

Soil	Film§ 1	2	3	1,2	1,3	1,2,3
----------Undulating Landscapes----------						
Bonilla (9)	0				33	
Clarno (17)	88				88	
Ethan (10)	50				70	
Over-all (36)	56				69	
----------Clarno-Bonilla Complex----------						
Clarno (17)	71					
Bonilla (17)	65					
Over-all (34)	68					
----------Clarno-Ethan Complex----------						
Clarno (8)	75				75	
Ethan (9)	67				89	
Over-all (17)	71				82	

†Number in parenthesis refers to the number of observations for that soil.

§Film combinations

1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

characteristics.

When a combination of the panchromatic (600-700 nm) (1) and infrared (700-900 nm) (3) was used in areas covered with crop residue the percent of the Bonilla and Ethan soils classified correctly increased to 33 and 70 percent respectively although the percent of the Clarno soil classified correctly was unchanged for an over-all accuracy of 69 percent. The combination of the panchromatic (600-700 nm) (1) and the infrared (700-900 nm) (3) films resulted in greater separation between the Bonilla and the Clarno soil and the Clarno and the Ethan soil due to a greater difference between mean transmission values for the Ethan soil than the Clarno soil and the Clarno soil than the Bonilla soil. The separation was increaed between the Bonilla and Clarno soils even though the mean transmission values for the two soils using the infrared (700-900 nm) film were similar. The percent of correct classification of the Clarno was higher than that of the Bonilla and Ethan soils partially due to the greater prior probability of the Clarno soil.

Clarno and Bonilla Soils Within the Clarno-Bonilla Complex

The panchromatic (600-700 nm) film was the most useful film for discriminating the Clarno and Bonilla soils within the Clarno-Bonilla complex on nearly level and undulating landscapes covered with crop residue. Seventy-one percent of the Clarno soil and 65 percent of the Bonilla soil were classified correctly resulting in an over-all accuracy of 68 percent.

It is interesting to note that no Bonilla data points were correctly classified using only the panchromatic (600–700 nm) (1) film on undulating landscapes. The Clarno and Bonilla data points showed little separation on undulating landscapes covered with crop residue. This points out the observation that discrimination of soils within a soil grouping is easier when fewer soil classes are considered especially if the soils have closely related spectral characteristics.

Clarno and Ethan Soils Within the Clarno-Ethan Complex

The panchromatic (600–700 nm) (1) film was the most useful single film for discriminating Clarno and Ethan soils within the Clarno-Ethan complex covered with crop residue. The Clarno and Ethan soils were correctly classified with a 75 and 67 percent accuracy respectively resulting in an over-all accuracy of 71 percent.

The percent of the Clarno and Ethan soils within the Clarno-Ethan complex classified correctly was increased to 75 and 89 percent respectively, using a combination of panchromatic (600–700 nm) (1) and infrared (700–900 nm) (3) film, giving an over-all accuracy of 82 percent. The combination of the panchromatic (600–700 nm) (1) and infrared (700–900 nm) (3) films resulted in greater separation of the Clarno and Ethan soils.

Stepwise Discriminant Analysis Within Each Soil Grouping with Growing Alfalfa

The panchromatic (500–700 nm) (2) film revealed the greatest differences among soils on undulating landscapes and within the Clarno-Ethan complex with growing alfalfa whereas the panchromatic

(600–700 nm) (1) film reveals the greatest differences among soils on nearly level landscapes and within the Clarno-Crossplain-Davison complex (Table 5). Initial entry r^2 values were .17 and .24 for the panchromatic (600–700 nm) (1) and Panchromatic (500–700 nm) (2) film respectively in the undulating landscape grouping and .14 and .18 for the Panchromatic (600–700 nm) (1) and Panchromatic (500–700 nm) (2) films respectively in the Clarno-Ethan complex grouping. In both cases the initial entry r^2 value for the panchromatic (500–700 nm) (2) was higher than that of the other two films. As a result the panchromatic (500–700 nm) (2) film variable was entered first. After the panchromatic (500–700 nm) (2) film variable was entered the partial r^2 of the panchromatic (600–700 nm) (1) film was not significant at the entry level. Little difference was measured between the transmission means of the Clarno and Ethan soils using the infrared (700–900 nm) film with growing alfalfa. This would indicate little difference exists between the reflectance of the alfalfa canopy on the Clarno and Ethan soils. The distance between transmission means of the Clarno, Crossplain, and Davison soil was also greatest using the panchromatic (600–700 nm) film and the standard deviation was lowest using the panchromatic (500–700 nm) film (Table 10). In this case the initial entry level r^2 was .53 and .47 for the panchromatic (600–700 nm) (1) and the panchromatic (500–700 nm) (2) films respectively (Table 5). Both were significant at the 0.01 level. Therefore within the undulating landscape, Clarno-Ethan complex, and the Clarno-Crossplain-Davison complex, little difference exists between the panchromatic (600–700 nm) (1) and the panchromatic (500–700 nm) (2) films in revealing difference among soils within the respective groupings. None of the films had a significant r^2 at the entry level with the Clarno-Bonilla complex. This is due mainly to the similarity of alfalfa growth on the Clarno and Bonilla soils.

The infrared (700-900 nm) (3) film did not reveal additional significant differences among soils. This is due partially to the large amount of near infrared light reflected by the relatively uniform alfalfa canopy. The nearly uniform reflectance of near-infrared radiation causes the mean film transmission values for the Clarno and Ethan soils to be similar. The relatively high reflectance and low absorption of near-infrared radiation of plant leaves is caued by reflectance of the spongy mesophyll and pallisade cells, has been noted by many researchers (Colwell, 1974; Gates et al., 1965; Knipling, 1970; Myers et al., 1966; Sinclair et al., 1971; and Sinclair et al., 1973).

Discriminant Classification of Soils with Growing Alfalfa

Undulating Landscapes and Clarno-Ethan Complex

The panchromatic (500-700 nm) (2) was the most useful film for discriminating soils on undulating landscapes and within the Clarno-Ethan complex with growing alfalfa (Table 13). The percent of the Clarno and Ethan soils classified correctly was higher within undulating landscapes than within the Clarno-Ethan complex. This is due to a slightly greater separation between the mean transmission values of the Clarno and Ethan soils and lower standard deviation on

Table 13. Percent soils classified correctly by soil grouping with growing alfalfa.†

	Film§					
Soil	1	2	3	1,2	1,3	1,2,3
---Undulating Landscapes---						
Clarno (13)		69				
Ethan (20)		80				
Over-all (33)		76				
---Nearly Level Landscapes---						
Bonilla (9)	11					
Clarno (16)	69					
Crossplain (8)	88					
Davison (10)	30					
Over-all (43)	51					
---Clarno-Ethan Complex---						
Clarno (12)		67				
Ethan (14)		64				
Over-all (26)		65				
---Clarno-Crossplain-Davison Complex---						
Clarno (7)	71					
Crossplain (8)	88					
Davison (10)	60					
Over-all (25)	72					

†Number in parenthesis refers to the number of observations for that soil.

§Film combinations

1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

the undulating landscapes than within the Clarno-Ethan complex (Tables 6 and 9).

Nearly Level Landscapes and Clarno-Crossplain-Davison Complex

The panchromatic (600-700 nm) (1) film was the most useful single film for discriminating soils on nearly level landscapes and within the Clarno-Crossplain-Davison complex with growing alfalfa. The Crossplain soil had a higher percent correct classification, partially because of the comparatively low standard deviation among data points (Tables 7 and 10). There was complete separation of the Crossplain and Davison soils (Appendix C, Tables 8 and 13). The main confusion that existed was between the Crossplain and Clarno soils, Crossplain and Bonilla soils and the Davison and Clarno soils. This is due to the greater similarity of alfalfa growth among the Crossplain, Bonilla an Clarno soils than between the Davison and Crossplain soils.

The over-all accuracy in discriminating soils in areas with growing alfalfa was greater on undulating landscapes than nearly level landscapes with an over-all accuracy of 76 and 51 percent respectively (Table 13). The lower percent classification may be due to more similarities of alfalfa in the soils on nearly level landscapes than undulating landscapes as well as a greater number of soil classes separations attempted on the nearly level landscapes.

The over-all accuracy in discriminating soils in areas with growing alfalfa was greater on soils within the Clarno-Crossplain-Davison complex than within nearly level landscapes with an over-all accuracy of 72 and 51 percent respectively. The higher percent over-all classification is due in part to fewer soil classes separations attempted within the Clarno-Crossplain-Davison complex than within nearly level landscapes.

Stepwise Discriminant Analysis Within Each Soil Grouping in Pasture

The infrared (700-900 nm) (3) film revealed the greatest differences among the soils within the undulating landscapes in pasture (Table 5). This may be due to the greater distance between the mean transmission values of the Worthing soil and the other soils using the infrared (700-900 nm) film than using the other two films. Most of the range species growing on the Worthing soil were still dormant; however, cool season species on the well drained sites were growing. Many areas of the Worthing soil were saturated or ponded. The infrared film is also more sensitive to differences in moisture content of the Worthing soil compared to that of the Clarno, Ethan, and Betts soils than the panchromatic films.

None of the films revealed significant differences between the Clarno and Ethan soils within the Clarno-Ethan complex because the transmission means of the two soils were close together (Table 9). Both soils are silty range sites and support similar vegetation (Kunze, 1982). Overgrazed ranges or fields planted to a single sepcies were covered by especially uniform vegetation.

Discriminant Classification of Soils on Undulating Landscapes in Pasture

The infrared (700-900 nm) (3) film was the most useful film for discriminating soils on undulating landscapes in pasture (Table 14). Ninety-four percent of the Ethan soil and 58 percent of the Worthing soil was classified correctly for an over-all accuracy of 48 percent. No observations of the Clarno and Betts soils were classified correctly. The very poorly drained Worthing soil had some separation from the well drained Clarno, Ethan and Betts soils, but little separation was found among the Clarno, Ethan and Betts soils (Appendix C, Table 10). The relatively uniform reflection characteristics of the vegetation resulted in a great amount of overlap in the Clarno, Ethan and Betts soils. Most of the data points of these three soils were classified as Ethan soil partially due to the greater prior probability of the Ethan soil.

Stepwise Discriminant Analysis

Within Each Soil Grouping with Growing Small Grain

The panchromatic (600-700 nm) (1) film revealed the greatest differences among soils in areas planted to small grain on all soil groupings tested (Table 5). This is due to greater separation of the transmission means of the soils using the panchromatic (600-700 nm) film than the panchromatic (500-700 nm) or infrared (700-900 nm) films (Tables 6, 8 and 9). The panchromatic (600-700 nm) (1) film had the

Table 14. Percent soils classified correctly by soil grouping in pasture.†

	Film§					
Soil	1	2	3	1,2	1,3	1,2,3
---Undulating Landscapes---						
Clarno (9)			0			
Ethan (17)			94			
Worthing (12)			58			
Betts (10)			0			
Over-all (48)			48			

†Number in parenthesis refers to the number of observations for that soil.

§Film combinations

1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

highest r^2 of the three films. No other film revealed significant additional differences among soils. The panchromatic (600–700 nm) (1) film showed differences between soils of the Clarno–Bonilla complex significant at the .15 entry level but not at the .05 significance level and was removed. The panchromatic (600–700 nm) film revealed greater differences among soils than the other two films due to differences in chlorophyll absorption of small grain on the various soils as well as the background soil reflection which was generally more contrasting using the panchromatic (600–700 nm) film.

Discriminant Classification of Soils with Growing Small Grain

Undulating Landscapes

The panchromatic (600–700 nm) (1) film was the most useful film for discriminating soils on undulating landscapes with growing small grain (Table 15). The Clarno and Ethan soils were classified correctly with 61 and 68 percent accuracy respectively resulting in an over-all accuracy of 52 percent. None of the data points of Bonilla or Betts soil were classified correctly using a single film. The Bonilla soil data points were classified as Clarno and Ethan soil (Appendix C, Table 14). This is due to the overlap of the Bonilla soil with the Clarno and Ethan soils as well as the greater prior probability of membership of the Clarno and Ethan soils. The small grain growth would be similar at this growth stage and background soil characteristics of the Clarno and Bonilla soils are also similar. All of the Betts data points were classified as Ethan soil due to the overlap of data points due to similarity of growth of small grain on

Table 15. Percent soils classified correctly by soil grouping with growing small grain.†

Soil	Film§ 1	2	3	1,2	1,3	1,2,3
Undulating Landscapes						
Bonilla (13)	0					
Clarno (31)	61					
Ethan (38)	68					
Betts (4)	0					
Over-all (86)	52					
Clarno-Ethan Complex						
Clarno (18)	67					
Ethan (24)	71					
Over-all (42)	69					

†Number in parenthesis refers to the number of observations for that soil.

§Film combinations

1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

these two soils as well as the greater prior probability of membership in the Ethan soil.

Clarno and Ethan Soils Within the Clarno-Ethan Complex

The panchromatic (600–700 nm) (1) film was the most useful film for discriminating the Clarno and Ethan soils within the Clarno-Ethan complex (Table 15). The Clarno and Ethan soils were classified correctly with 67 and 71 percent accuracy respectively resulting in an over-all accuracy of 69 percent. The major reason for the higher over-all accuracy for discriminating soils within the Clarno-Ethan complex than within undulating landscapes is that fewer soil classes are being within the Clarno-Ethan complex compared resulting in less overlap among soils.

CONCLUSIONS

Panchromatic film filtered for the 500-700 nm and 500-700 nm wavelengths and infrared film filtered for the 700-900 nm wavelength were evaluated to determine if tonal differences exist among the three film types either singularly or in combination that would allow discrimination of soil series within landscapes and mapping unit complexes on the land cover present.

The panchromatic (600-700 nm) film revealed the greatest differences among the soils in areas with no land cover using a single film within each soil grouping except within the Clarno-Crossplain-Davison complex. Combinations of films were useful in areas with no land cover especially on the landscape units where differences among soils occur. The panchromatic (500-700 nm) film added more discriminating power to the discriminant model than the infrared (700-900 nm) film.

The coefficient of determination was highest for soil groupings with the greatest spectral differences among soil classes resulting mainly from differences in surface organic matter and moisture content, Munsell color, and mineralogical composition.

The panchromatic (600-700 nm) film revealed the greatest differences among soils in areas covered with crop residue using a single film. The coefficient of determination was increased by using a combination of panchromatic (600-700 nm) film and panchromatic (700-900 nm) films in areas where differences among the soils within a soil groupings were greatest.

Either the panchromatic (600-700 nm) or the panchromatic

(500–700 nm) film was most useful in revealing the differences among soils on soils with growing alfalfa. The initial entry r^2 values were generally similar for both the panchromatic (600–700 nm) and the panchromatic (500–700 nm) films. On soils where alfalfa growth was similar such as within the Clarno-Bonilla complex, none of the films revealed significant differences between soils.

The infrared (700–900 nm) film revealed the greatest differences among soils in pasture within undulating landscapes where the reflectance characteristics of the grasses among soils were contrasting. None of the films were useful in explaining differences between soils within the Clarno-Ethan complex due to similarity of reflectance from the vegetation on the two soils.

The panchromatic (600–700 nm) film revealed the greatest differences among soils in areas planted to small grain within undulating landscapes and the Clarno-Ethan complex due to differences in the small grain growth as well as background soil reflection. None of the films were useful in revealing significant differences between the Clarno and Bonilla soils with growing small grain due to greater similarity in crop growth and soil background characteristics.

Over-all accuracy of detecting soils is increased by reducing the area of consideration from landscape units to complexes. Over-all accuracy of landscapes and complexes was 56 and 69 percent respectively. The higher over-all accuracy in detecting soils within complexes is partially a result of fewer soil classes compared. The highest accuracy of distinguishing soils within complexes is achieved when the soils within the complex have contrasting surface spectral properties. Using film transmission techniques would be a useful soil survey tool within complexes if the components have contrasting spectral reflectances with the land cover present. In an agricultural area if only film will be used, the panchromatic (600–700 nm) film would be the most useful single film in soil survey activities. In areas where conservation tillage practices leave crop residue on the surface, a combination of the panchromatic (600–700 nm) and infrared (700–900 nm) films would aid in making high quality soil maps. The use of infrared film may be useful among very contrasting moisture content or support vegetation with contrasting spectral properties.

In areas with several types of land cover, soil identification and mapping would be most accurate when the soil scientist refers to more than one type of photography in soil survey activities. The soil scientist should be knowledgeable of the film or combination of films that most accurately detects the types of soils present with the land cover types common in the survey area.

REFERENCES

Aase, J. K. and F. H. Siddoway. 1980. Determining winter wheat stand densities using spectral reflectance measurements; Agronomy Journal 72:149-152.

Bowers, S. A. and R. J. Hanks. 1965. Reflection of radiant energy from soils. Soil Science 100:130-138.

Benson, L. A. 1973. Reflectance Measurements for the Detection and Mapping of Soil Limitations. M. S. Thesis, South Dakota State University.

Colwell, J. E. 1974. Vegetation canopy reflectance. Remote Sensing of Environment 3:175-183.

Condit, H. R. 1970. The spectral reflectance of American soils. Photogrammetric Engineering 36:955-966.

Eastman Kodak Company. 1970. Kodal Wratten Filters for Scientific and Technical Use. Kodak Publication B-3, Rochester, New York.

Eastman Kodak Company. 1972a. Kodak Aerial Films and Photographic Plates. Kodak Publication M-61, Rochester, New York.

Eastman Kodak Company. 1972b. Physical Properties of Kodak Aerial Films. Kodak Publication M-62, Rochester, New York.

Evans, R. Air photos for soil survey in lowland England: factors affecting the photographic images of bare soil and their relevance to assessing soil moisture content and discrimination of soils by remote sensing. Remote Sensing of Environment 8:39-63.

Flint, R. F. 1955. Pleistocene Geology of Eastern South Dakota. U. S. Dept. of Interior Geological Survey Professional Paper 262, Washington, D. C.

Frazee, C. J., F. C. Westin, J. L. Gropper and V. I. Myers. 1972. Remote Sensing of Soils, Land Forms, and Land Use in the Northern Great Plains in Preparation for ERTS Applications, Remote Sensing Institute, South Dakota State University.

Frazee, C. J., R. L. Carey, and F. C. Westin. 1972. Utilizing remote sensing data for land use decisions for Indian land in South Dakota. Proceedings of the 8th Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp. 375-391.

Gates, D. M. 1965. Characteristics of soil and vegetated surfaces to reflected and emitted radiation. Proceedings of the 3rd Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. Pp. 573-600.

Gates, D. M., H. J. Keegan, J. C. Schleter, and V. R. Weidner. 1965. Spectral properties of plants. Applied Optics 4:11-20.

Gausman, H. W., A. H. Gerbermann, C. L. Wiegand, R. W. Leamer, R. R. Rodriguez and J. R. Noriega. 1975. Reflectance differences between crop residues and bare soils. Soil Science Society of America Journal 39:752-755.

Gausman, H. W., R. R. Rodriguez and A. J. Richardson. 1976. Infinite reflectance of dead compared with live vegetation. Agronomy Journal 68:295-296.

Gausman, H. W., R. W. Leamer, J. R. Noriega, R. R. Rodriguez and C. L. Weigand. 1977. Field-measured spectoradiometric reflectances of disked and nondisked soil with and without wheat straw. Soil Science Society of America Journal 41:793-796.

Gerbermann, A. H. 1979. Reflectane of varying mixtures of a clay soil and sand. Photogrammetric Engineering and Remote Sensing 45:1145-1151.

Hoffer, R. M., R. A. Holmes and J. R. Shay. 1966. Vegetative, soil and photographic factors affecting tone in agricultural remote multispectral sensing. Proceedings of the 4th Symposium on Remote Sensing of Environment, April 12-14, 1966, Ann Arbor, Michigan. Pp. 115-134.

Hovis, W. A. Jr. 1966. Infrared spectral reflectance of some common minerals. Applied Optics 5:245-247.

Knipling, E. B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing of Environment 1:155-159.

Kornblau, M. L. and J. E. Cirpa. 1983. Investigation of digital Landsat data for mapping soils under range vegetation. Remote Sensing of Environment 13:103-112.

Kristof, S. J. and A. L. Zachary. 1974. Mapping soil features from multispectral scanner data. Photogrammetric Engineering 40:1427-1434.

Kristof, S. J. and M. F. Baumgardner. 1975. Changes of multispectral soil patterns with increasing crop canopy. Agronomy Journal 67:317-321.

Sinclair, T. R., M. M. Schreiber, and R. M. Hoffer. 1973. Diffuse reflectance hypothesis for the pathway of solar radiation through leaves. Agronomy Journal 65:276-283.

Soil Conservation Service. 1979. South Dakota Technical Guide for Land Resource Areas 102A & 102B. Huron, South Dakota.

Soil Survey Staff. 1975. Soil Taxonomy -- a basic system of soil classification for making and interpreting soil survey. Soil Conservation Service, U. S. Dept. of Agriculture, Agricultural Handbook No. 436, Washington, D. C.

Soil Survey Staff. 1982. Soil Series of the United States, Puerto Rico, and the Virgin Islands. Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C.

Specht, M. R. 1970. IR and pan films. Photogrammetric Engineering 36:360-364.

Stoner, E. R. and M. F. Baumgardner. 1981. Characteristic variations in reflectance of surface soils. Soil Science Society of America Journal 45:1161-1165.

Suits, G. H. 1983. Extension of a uniform canopy reflectance model to include row effects. Remote Sensing of Environment 13:113-129.

Tucker, C. J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8:127-150.

Tucker, C. J., J. H. Elgin, Jr., J. E. McMurtrey III, and C. J. Fan. 1979. Monitoring corn and soybean crop development with hand-held radiometer spectral data. Remote Sensing of Environment 8:237-248.

United States Geological Survey, Topographic Division. 1979. Specifications for Interagency high-altitude aerial photography, USGS SPEC 79-30, United States Department of Interior, Restin, Va.

Valentine, K. W. G., T. M. Lord, W. Watt, and A. L. Bedwany. 1971. Soil mapping from black and white, color, and infrared aerial photography. Canadian Journal of Soil Science 51:461-469.

Westin, F. C. 1975. Soil Surveys for identifying soil associations. IN: Manual of Remote Sensing, American Society of Photogrammetry, Falls Church, Virginia. Pp. 1755-1764.

Westin, F. C. and C. J. Frazee. 1976. LANDSAT data, its use in a soil survey program. Soil Science Society of America Journal 40:81-89.

Westin, F. C. and G. D. Lemme. 1978. LANDSAT spectral signatures: studies with soil associations and vegetation. Photogrammetric Engineering and Remote Sensing 44:315-325.

Westin, F. C. and V. I. Myers. 1973. Identification of Soil Associations in Western South Dakota. Plant Science Department and Remote Sensing Institute, South Dakota State University.

APPENDIX A

FILM TRANSMISSION DATA
BY SOIL AND LAND COVER

Table 1. Film transmission data by soil and land cover.

ID.	1	2	3	Map Unit	Soil	Land Cover
5100508	121	116	78	9†	Bonilla	No Cover
5120803	119	111	73	9	Bonilla	No Cover
5152005	120	112	82	9	Bonilla	No Cover
5152102	118	110	78	9	Bonilla	No Cover
5162804	105	101	67	9	Bonilla	No Cover
5173209	112	109	67	9	Bonilla	No Cover
5173304	111	105	75	9	Bonilla	No Cover
5183302	111	105	71	9	Bonilla	No Cover
5190403	107	103	67	9	Bonilla	No Cover
5190405	110	104	69	9	Bonilla	No Cover
5109408	113	104	77	9	Bonilla	No Cover
5190505	104	96	61	9	Bonilla	No Cover
3132502	110	98	67	9	Bonilla	No Cover
3160106	112	99	76	9	Bonilla	No Cover
3160101	85	79	54	9	Bonilla	No Cover
3160204	125	112	82	9	Bonilla	No Cover
3171102	113	105	71	9	Bonilla	No Cover
3171103	112	99	68	9	Bonilla	No Cover
3171202	101	97	66	9	Bonilla	No Cover
3212604	112	99	63	9	Bonilla	No Cover
3224504	114	105	75	9	Bonilla	No Cover
5062002	120	109	71	9	Bonilla	No Cover
5082903	114	109	56	9	Bonilla	No Cover
1212101	106	98	77	9	Bonilla	No Cover
1243204	98	97	66	9	Bonilla	No Cover
3131410	114	103	80	9	Bonilla	No Cover
5173204	107	98	92	9	Bonilla	Crop Residue
5173206	126	115	75	9	Bonilla	Crop Residue
5173207	128	119	83	9	Bonilla	Crop Residue
5173306	130	123	90	9	Bonilla	Crop Residue
3160110	133	121	89	9	Bonilla	Crop Residue
3171213	123	109	80	9	Bonilla	Crop Residue
3192401	104	111	85	9	Bonilla	Crop Residue
3223502	127	114	98	9	Bonilla	Crop Residue

†Clarno-Bonilla loams, 0 to 2 percent slopes

#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
5190401	66	83	172	9†	Bonilla	Alfalfa
3153502	67	77	132	9	Bonilla	Alfalfa
3160108	69	108	124	9	Bonilla	Alfalfa
3160202	87	92	128	9	Bonilla	Alfalfa
3171205	43	70	116	9	Bonilla	Alfalfa
3192305	71	78	143	9	Bonilla	Alfalfa
5093215	93	100	140	9	Bonilla	Alfalfa
1212104	64	77	114	9	Bonilla	Alfalfa
3021108	70	83	144	9	Bonilla	Alfalfa
5152003	128	121	99	9	Bonilla	Small Grain
5152105	122	113	106	9	Bonilla	Small Grain
5162801	115	112	115	9	Bonilla	Small Grain
5162805	115	109	106	9	Bonilla	Small Grain
5162905	125	115	99	9	Bonilla	Small Grain
5162908	129	122	114	9	Bonilla	Small Grain
5173217	120	116	108	9	Bonilla	Small Grain
5173221	126	120	110	9	Bonilla	Small Grain
5173302	131	125	124	9	Bonilla	Small Grain
5190409	118	113	96	9	Bonilla	Small Grain
5190506	106	106	108	9	Bonilla	Small Grain
3153602	106	101	117	9	Bonilla	Small Grain
3171204	91	107	108	9	Bonilla	Small Grain
3181410	89	101	87	9	Bonilla	Small Grain
3181415	124	110	99	9	Bonilla	Small Grain
3212606	130	115	110	9	Bonilla	Small Grain
5051701	115	111	84	9	Bonilla	Small Grain
5093213	120	120	95	9	Bonilla	Small Graine
1243304	100	97	100	9	Bonilla	Small Graine
5110402	111	106	74	10§	Bonilla	No Cover
5142012	112	105	77	10	Bonilla	No Cover
5162911	124	116	86	10	Bonilla	No Cover
3091202	116	105	86	10	Bonilla	No Cover
3181304	113	100	75	10	Bonilla	No Cover
3181407	121	108	84	10	Bonilla	No Cover
3192302	113	98	64	10	Bonilla	No Cover

†Clarno-Bonilla loams, 0 to 2 percent slopes
§Clarno-Bonilla loams, 2 to 6 percent slopes
#Film combinations
 1 Panchromatic (600-700 nm)
 2 Panchromatic (500-700 nm)
 3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	Film # 2	Film # 3	Map Unit	Soil	Land Cover
3192306	100	88	55	10†	Bonilla	No Cover
3031313	113	102	63	10	Bonilla	No Cover
3031315	118	105	67	10	Bonilla	No Cover
3021408	117	103	78	10	Bonilla	No Cover
3031303	98	90	61	10	Bonilla	No Cover
5142101	126	115	84	10	Bonilla	Crop Residue
3122311	142	127	100	10	Bonilla	Crop Residue
3181413	128	112	90	10	Bonilla	Crop Residue
3192309	133	113	85	10	Bonilla	Crop Residue
5100501	126	116	75	10	Bonilla	Crop Residue
1201705	140	128	101	10	Bonilla	Crop Residue
3021106	128	113	89	10	Bonilla	Crop Residue
3021411	135	118	89	10	Bonilla	Crop Residue
5173223	129	118	85	10	Bonilla	Crop Residue
3122403	72	80	149	10	Bonilla	Alfalfa
5110502	132	125	116	10	Bonilla	Small Grain
5110503	135	128	118	10	Bonilla	Small Grain
5131702	105	106	102	10	Bonilla	Small Grain
5142001	105	106	107	10	Bonilla	Small Grain
5142010	112	117	107	10	Bonilla	Small Grain
5173202	117	110	96	10	Bonilla	Small Grain
5173224	115	111	102	10	Bonilla	Small Grain
3052502	104	102	103	10	Bonilla	Small Grain
3101414	122	108	102	10	Bonilla	Small Grain
3181401	96	95	116	10	Bonilla	Small Grain
3223507	126	113	114	10	Bonilla	Small Grain
1222902	101	95	91	10	Bonilla	Small Grain
3031310	114	104	105	10	Bonilla	Small Grain
5120802	122	113	77	9§	Clarno	No Cover
5152006	124	116	87	9	Clarno	No Cover
5152103	121	112	83	9	Clarno	No Cover
5162803	116	109	78	9	Clarno	No Cover
5173210	115	108	70	9	Clarno	No Cover
5173303	113	109	80	9	Clarno	No Cover
5183301	119	109	73	9	Clarno	No Cover

†Clarno-Bonilla loams, 2 to 6 percent slopes
§Clarno-Bonilla loams, 0 to 2 percent slopes
#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	Film # 2	Film # 3	Map Unit	Soil	Land Cover
5190404	110	104	68	9†	Clarno	No Cover
5190406	113	105	70	9	Clarno	No Cover
5190407	121	113	90	9	Clarno	No Cover
5190504	109	101	65	9	Clarno	No Cover
3132501	118	103	70	9	Clarno	No Cover
3160105	117	105	80	9	Clarno	No Cover
3160112	90	83	56	9	Clarno	No Cover
3160205	129	114	85	9	Clarno	No Cover
3171101	123	108	75	9	Clarno	No Cover
3171104	119	103	73	9	Clarno	No Cover
3171201	107	99	68	9	Clarno	No Cover
5110507	128	120	81	9	Clarno	No Cover
3212603	114	99	65	9	Clarno	No Cover
3223503	123	107	78	9	Clarno	No Cover
5062001	124	113	75	9	Clarno	No Cover
5082902	114	111	57	9	Clarno	No Cover
1212102	110	103	81	9	Clarno	No Cover
1243203	102	100	64	9	Clarno	No Cover
3021202	117	105	82	9	Clarno	No Cover
3031411	112	100	87	9	Clarno	No Cover
3192301	125	104	71	10§	Clarno	No Cover
3181406	132	113	107	10	Clarno	No Cover
3192305	104	90	57	10	Clarno	No Cover
5110401	116	109	80	10	Clarno	No Cover
3181305	119	105	78	10	Clarno	No Cover
5142011	121	113	83	10	Clarno	No Cover
5162910	117	112	84	10	Clarno	No Cover
3031314	117	104	65	10	Clarno	No Cover
3031316	120	106	68	10	Clarno	No Cover
3091203	122	109	92	10	Clarno	No Cover
3131304	106	96	64	10	Clarno	No Cover
3021409	121	104	80	10	Clarno	No Cover
3122308	117	105	71	11¶	Clarno	No Cover
1212004	112	105	74	11	Clarno	No Cover
1222803	107	97	73	11	Clarno	No Cover

†Clarno-Bonilla loams, 0 to 2 percent slopes
§Clarno-Bonilla loams, 2 to 6 percent slopes
¶Clarno-Crossplain-Davison complex, 0 to 3 percent slopes
#Film combination

1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	Film # 2	Film # 3	Map Unit	Soil	Land Cover
3181301	118	106	80	11†	Clarno	No Cover
3171104	119	103	73	11	Clarno	No Cover
1030804	101	100	67	11	Clarno	No Cover
1100804	107	100	67	11	Clarno	No Cover
1041606	100	82	62	11	Clarno	No Cover
3192312	127	106	84	13§	Clarno	No Cover
3212609	135	116	85	13	Clarno	No Cover
5100506	122	116	80	13	Clarno	No Cover
3171212	96	93	67	13	Clarno	No Cover
3132602	113	101	70	13	Clarno	No Cover
3031403	116	99	84	13	Clarno	No Cover
3021203	109	103	90	13	Clarno	No Cover
3021110	114	103	80	13	Clarno	No Cover
3122303	116	109	72	13	Clarno	No Cover
3073508	113	103	70	13	Clarno	No Cover
5072100	107	81	63	13	Clarno	No Cover
5082805	116	108	57	14¶	Clarno	No Cover
5082807	109	108	115	14	Clarno	No Cover
5092204	110	102	60	14	Clarno	No Cover
5093208	127	121	81	14	Clarno	No Cover
1243302	102	98	68	14	Clarno	No Cover
3042302	116	105	78	14	Clarno	No Cover
3021104	116	182	82	14	Clarno	No Cover
3021413	99	92	93	14	Clarno	No Cover
3181307	89	80	93	14	Clarno	No Cover
3153507	127	108	84	14	Clarno	No Cover
3161206	125	106	79	14	Clarno	No Cover
3073605	119	100	67	14	Clarno	No Cover
3080202	104	105	80	14	Clarno	No Cover
3042304	114	95	76	14	Clarno	No Cover
5162901	133	121	85	14	Clarno	No Cover
5131602	138	126	96	14	Clarno	No Cover
5131604	123	119	101	14	Clarno	No Cover
5131606	118	111	89	14	Clarno	No Cover
5173203	129	117	177	9††	Clarno	Crop Residue

†Clarno-Crossplain-Davison comlex, 0 to 3 percent slopes
§Clarno-Ethan loams, 2 to 6 percent slopes
¶Clarno-Ethan loams, 5 to 9 percent slopes
††Clarno-Bonilla loams, 0 to 2 percent slopes
#Film combinations
  1 Panchromatic (600-700 nm)
  2 Panchromatic (500-700 nm)
  3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
5173205	134	124	85	9†	Clarno	Crop Residue
5173208	141	128	91	9	Clarno	Crop Residue
5173305	138	124	92	9	Clarno	Crop Residue
3160109	128	111	82	9	Clarno	Crop Residue
3171214	117	117	87	9	Clarno	Crop Residue
3192402	134	120	100	9	Clarno	Crop Residue
3223501	137	122	87	9	Clarno	Crop Residue
5142102	130	118	85	10§	Clarno	Crop Residue
3181412	135	118	89	10	Clarno	Crop Residue
3192310	134	115	92	10	Clarno	Crop Residue
3122312	149	131	104	10	Clarno	Crop Residue
5173222	141	127	93	10	Clarno	Crop Residue
1201704	141	128	97	10	Clarno	Crop Residue
3021105	137	120	99	10	Clarno	Crop Residue
5100502	128	117	76	10	Clarno	Crop Residue
3021410	140	121	92	10	Clarno	Crop Residue
3052603	114	102	60	12¶	Clarno	Crop Residue
3073603	126	111	86	13††	Clarno	Crop Residue
3122393	131	116	86	13	Clarno	Crop Residue
3132503	129	112	82	13	Clarno	Crop Residue
3132609	134	116	88	13	Clarno	Crop Residue
1170501	115	105	66	13	Clarno	Crop Residue
3031305	117	105	73	13	Clarno	Crop Residue
5162913	151	137	105	14§§	Clarno	Crop Residue
5093209	141	129	92	14	Clarno	Crop Residue
5190402	69	85	140	9†	Clarno	Alfalfa
3153501	75	80	117	9	Clarno	Alfalfa
3160107	75	115	120	9	Clarno	Alfalfa
3160203	91	94	124	9	Clarno	Alfalfa
3171206	56	81	113	9	Clarno	Alfalfa
3192303	81	85	138	9	Clarno	Alfalfa
5093216	100	106	131	9	Clarno	Alfalfa
1212103	65	80	142	9	Clarno	Alfalfa
3021107	76	87	148	9	Clarno	Alfalfa
3122402	76	86	140	10§	Clarno	Alfalfa
1132006	77	86	116	11¶¶	Clarno	Alfalfa
2582801	80	87	135	11	Clarno	Alfalfa

†Clarno-Bonilla loams, 0 to 2 percent slopes
§Clarno-Bonilla loams, 2 to 6 percent slopes
¶Clarno-Davison loams, 2 to 5 percent slopes
††Clarno-Ethan loams, 2 to 6 percent slopes
§§Clarno-Ethan loams, 5 to 9 percent slopes
¶¶Clarno-Crossplain-Davison complex, 0 to 3 percent slopes

#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
2532103	73	86	136	11†	Clarno	Alfalfa
1212009	83	84	139	11	Clarno	Alfalfa
3532106	76	88	140	11	Clarno	Alfalfa
2513401	80	88	126	11	Clarno	Alfalfa
2541602	74	87	126	11	Clarno	Alfalfa
3080101	78	85	137	13§	Clarno	Alfalfa
3032302	112	88	128	13	Clarno	Alfalfa
3080210	92	92	124	13	Clarno	Alfalfa
3122302	82	87	111	13	Clarno	Alfalfa
3160104	71	78	127	13	Clarno	Alfalfa
3212601	93	88	122	13	Clarno	Alfalfa
5051704	86	94	125	13	Clarno	Alfalfa
3021101	91	95	126	14¶	Clarno	Alfalfa
3021402	60	73	125	14	Clarno	Alfalfa
3091111	69	76	74	14	Clarno	Alfalfa
3073507	74	85	145	14	Clarno	Alfalfa
5152001	103	107	135	14	Clarno	Alfalfa
5100402	139	131	115	10††	Clarno	Pasture
5173219	112	109	116	10	Clarno	Pasture
3101303	117	101	73	10	Clarno	Pasture
1121701	104	105	100	11†	Clarno	Pasture
3101405	92	92	121	13§	Clarno	Pasture
3171210	103	101	117	13	Clarno	Pasture
3132608	116	104	112	14¶	Clarno	Pasture
3160102	109	100	120	14	Clarno	Pasture
1243208	111	108	116	14	Clarno	Pasture
3081206	106	98	112	14	Clarno	Pasture
3031412	121	112	141	14	Clarno	Pasture
5152104	130	122	114	9§§	Clarno	Small Grain
5162802	119	114	112	9	Clarno	Small Grain
5162807	125	116	109	9	Clarno	Small Grain
5162906	132	121	101	9	Clarno	Small Grain
5162909	134	124	118	9	Clarno	Small Grain
5173216	128	120	111	9	Clarno	Small Grain
5173220	128	123	113	9	Clarno	Small Grain

†Clarno-Crossplain-Davison comlex,
0 to 3 percent slopes
§Clarno-Ethan loams, 2 to 6 percent slopes
¶Clarno-Ethan loams, 5 to 9 percent slopes
††Clarno-Bonilla loams, 2 to 6 percent slopes
§§Clarno-Bonilla loams, 0 to 2 percent slopes

#Film combinations
1 Panchromatic (600-700 nm
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
5173301	136	129	128	9†	Clarno	Small Grain
5190410	124	115	95	9	Clarno	Small Grain
3153601	109	103	114	9	Clarno	Small Grain
3171203	101	113	109	9	Clarno	Small Grain
3182409	114	104	83	9	Clarno	Small Grain
3181414	130	118	109	9	Clarno	Small Grain
3212607	133	120	111	9	Clarno	Small Grain
5051702	117	111	83	9	Clarno	Small Grain
5093214	128	114	93	9	Clarno	Small Grain
1243303	106	102	101	9	Clarno	Small Grain
3031309	119	110	109	10§	Clarno	Small Grain
5110501	138	130	120	10	Clarno	Small Grain
5110504	139	131	121	10	Clarno	Small Grain
3052501	108	103	100	10	Clarno	Small Grain
3073505	104	99	112	10	Clarno	Small Grain
5173225	125	117	111	10	Clarno	Small Grain
5131701	112	110	109	10	Clarno	Small Grain
5142002	110	110	109	10	Clarno	Small Grain
5142009	124	121	105	10	Clarno	Small Grain
1222901	107	97	93	10	Clarno	Small Grain
3223508	131	117	110	10	Clarno	Small Grain
3181402	104	100	110	10	Clarno	Small Grain
5173201	124	117	99	10	Clarno	Small Grain
3122316	111	106	116	13¶	Clarno	Small Grain
3080203	91	101	112	13	Clarno	Small Grain
3192404	103	95	103	13	Clarno	Small Grain
3101401	101	103	97	13	Clarno	Small Grain
1090402	115	106	103	13	Clarno	Small Grain
1243206	108	106	103	13	Clarno	Small Grain
5173211	115	106	86	13	Clarno	Small Grain
3031307	109	110	102	13	Clarno	Small Grain
3031311	126	109	96	13	Clarno	Small Grain

†Clarno-Bonilla loams, 0 to 2 percent slopes
§Clarno-Bonilla loams, 2 to 6 percent slopes
¶Clarno-Ethan loams, 2 to 6 percent slopes
#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
3032304	110	112	86	13†	Clarno	Small Grain
5173214	110	106	81	13	Clarno	Small Grain
5110405	136	124	108	14§	Clarno	Small Grain
5110404	132	122	102	14	Clarno	Small Grain
3042301	110	102	109	14	Clarno	Small Grain
3053509	127	114	101	14	Clarno	Small Grain
5062006	129	121	116	14	Clarno	Small Grain
5093302	130	118	84	14	Clarno	Small Grain
1243306	115	102	97	14	Clarno	Small Grain
1212002	108	104	71	11¶	Crossplain	No Cover
3122306	110	101	64	11	Crossplain	No Cover
3181303	114	101	73	11	Crossplain	No Cover
1222801	106	95	71	11	Crossplain	No Cover
3171106	121	107	76	11	Crossplain	No Cover
1030803	97	94	64	11	Crossplain	No Cover
1100802	102	97	65	11	Crossplain	No Cover
1041605	89	92	64	11	Crossplain	No Cover
5152101	112	105	68	15††	Crossplain	No Cover
3153505	108	96	64	15	Crossplain	No Cover
5082803	116	113	56	15	Crossplain	No Cover
3042405	95	89	60	15	Crossplain	No Cover
3031409	113	103	108	15	Crossplain	No Cover
1132008	70	83	126	11¶	Crossplain	Alfalfa
2582803	68	83	137	11	Crossplain	Alfalfa
2532101	71	85	148	11	Crossplain	Alfalfa
3532105	67	83	150	11	Crossplain	Alfalfa
3522802	68	85	151	11	Crossplain	Alfalfa
2513403	77	84	128	11	Crossplain	Alfalfa
2541603	66	80	131	11	Crossplain	Alfalfa
1212008	71	83	138	11	Crossplain	Alfalfa
3122307	122	107	72	11	Davison	No Cover
3171105	134	117	83	11	Davison	No Cover
3181302	130	112	82	11	Davison	No Cover
1212003	119	112	79	11	Davison	No Cover
1222802	112	105	78	11	Davison	No Cover
1030805	108	102	69	11	Davison	No Cover
1100803	122	112	85	11	Davison	No Cover
1041607	109	104	77	11	Davison	No Cover
1100807	82	88	125	11	Davison	Alfalfa

†Clarno-Ethan loams, 2 to 6 percent slopes
§Clarno-Ethan loams, 5 to 9 percent slopes
¶Clarno-Crossplain-Davison complex, 0 to 3 percent slopes
††Crossplain clay loam

#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
1132007	79	88	118	11†	Davison	Alfalfa
2582802	82	87	128	11	Davison	Alfalfa
2532102	78	91	134	11	Davison	Alfalfa
3532104	102	104	129	11	Davison	Alfalfa
3522801	74	88	141	11	Davison	Alfalfa
2513402	86	90	125	11	Davison	Alfalfa
2541601	83	90	124	11	Davison	Alfalfa
1212007	94	91	133	11	Davison	Alfalfa
1163205	80	87	129	11	Davison	Alfalfa
1062901	133	120	81	13§	Ethan	No Cover
307359	126	114	81	13	Ethan	No Cover
3122304	145	126	91	13	Ethan	No Cover
3132601	120	105	72	13	Ethan	No Cover
1072303	100	96	77	13	Ethan	No Cover
3031404	121	107	86	13	Ethan	No Cover
3021109	131	118	92	13	Ethan	No Cover
3021204	128	114	96	13	Ethan	No Cover
5072002	120	88	73	13	Ethan	No Cover
5100505	133	127	89	13	Ethan	No Cover
3171211	106	100	75	14¶	Ethan	No Cover
3192311	141	118	92	14	Ethan	No Cover
3212608	150	127	89	14	Ethan	No Cover
3223505	144	126	98	14	Ethan	No Cover
3223506	119	110	89	14	Ethan	No Cover
3042301	146	125	92	14	Ethan	No Cover
1083302	127	112	84	14	Ethan	No Cover
5131603	164	149	119	14	Ethan	No Cover
5131605	148	133	103	14	Ethan	No Cover
5162902	139	124	87	14	Ethan	No Cover
5131601	163	150	110	14	Ethan	No Cover
3042303	127	108	80	14	Ethan	No Cover
1180806	136	123	97	14	Ethan	No Cover
3073604	125	113	85	14	Ethan	No Cover
3080201	119	119	95	14	Ethan	No Cover
3153506	148	127	101	14	Ethan	No Cover

†Clarno-Crossplain-Davison complex,
0 to 3 percent slopes
§Clarno-Ethan loams, 2 to 6 percent slopes
¶Clarno-Ethan loams, 5 to 9 percent slopes
#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
3160207	134	122	91	14†	Ethan	No Cover
5082804	127	121	65	14	Ethan	No Cover
5082806	114	111	111	14	Ethan	No Cover
5093203	129	120	70	14	Ethan	No Cover
5093207	133	122	77	14	Ethan	No Cover
5093301	147	134	91	14	Ethan	No Cover
1243301	129	118	89	14	Ethan	No Cover
3021103	151	132	100	14	Ethan	No Cover
3021412	119	104	96	14	Ethan	No Cover
3293506	124	109	77	20§	Ethan	No Cover
3293603	113	102	78	20	Ethan	No Cover
1323205	126	113	79	20	Ethan	No Cover
5040805	119	123	94	20	Ethan	No Cover
1250501	111	101	73	20	Ethan	No Cover
3272305	135	118	86	20	Ethan	No Cover
1282002	120	113	79	20	Ethan	No Cover
1271703	111	101	70	20	Ethan	No Cover
1302909	114	102	73	24¶	Ethan	No Cover
3293507	128	110	81	24	Ethan	No Cover
3282502	146	123	97	24	Ethan	No Cover
1323212	131	116	79	24	Ethan	No Cover
3282504	161	137	110	24	Ethan	Crop Residue
3073602	161	141	109	13††	Ethan	Crop Residue
3122310	154	134	102	13	Ethan	Crop Residue
3031306	132	116	82	13	Ethan	Crop Residue
3132504	146	123	95	13	Ethan	Crop Residue
1170502	127	114	74	13	Ethan	Crop Residue
3132610	146	125	97	13	Ethan	Crop Residue
5093210	155	142	105	14†	Ethan	Crop Residue
1100904	134	119	91	14	Ethan	Crop Residue
5162912	173	153	122	14	Ethan	Crop Residue
1142902	97	98	134	13††	Ethan	Alfalfa
1142905	80	86	128	13	Ethan	Alfalfa
1170402	111	116	120	13	Ethan	Alfalfa
3032301	118	99	116	13	Ethan	Alfalfa

†Clarno-Ethan loams, 5 to 9 percent slopes
§Egan-Ethan complex, 2 to 6 percent slopes
¶Ethan-Egan complex, 5 to 9 percent slopes
††Clarno-Ethan loams, 2 to 6 percent slopes
#Film combinations
  1 Panchromatic (600-700 nm)
  2 Panchromatic (500-700 nm)
  3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
3122301	99	97	109	13†	Ethan	Alfalfa
3160103	72	79	123	13	Ethan	Alfalfa
3212602	119	105	120	13	Ethan	Alfalfa
5059703	97	102	122	13	Ethan	Alfalfa
3080102	81	87	144	13	Ethan	Alfalfa
3080211	101	98	173	13	Ethan	Alfalfa
5152002	117	119	133	14§	Ethan	Alfalfa
3073506	79	90	140	14	Ethan	Alfalfa
3091110	75	80	78	14	Ethan	Alfalfa
3021102	111	106	122	14	Ethan	Alfalfa
3293509	94	93	123	20¶	Ethan	Alfalfa
5040802	82	101	125	20	Ethan	Alfalfa
1323304	107	103	123	20	Ethan	Alfalfa
5082905	102	107	123	23††	Ethan	Alfalfa
3031406	93	101	130	23	Ethan	Alfalfa
3293511	106	99	123	24§§	Ethan	Alfalfa
3171209	107	104	120	13†	Ethan	Pasture
3101404	106	99	110	13	Ethan	Pasture
1170508	116	110	122	13	Ethan	Pasture
1090403	97	98	112	14§	Ethan	Pasture
1121603	126	120	109	14	Ethan	Pasture
1163207	104	99	116	14	Ethan	Pasture
3080205	118	104	114	14	Ethan	Pasture
3132607	123	109	112	14	Ethan	Pasture
3160101	111	101	113	14	Ethan	Pasture
1243207	112	108	113	14	Ethan	Pasture
3031413	135	121	135	14	Ethan	Pasture
3091112	128	114	127	23††	Ethan	Pasture
3153604	109	102	123	23	Ethan	Pasture
5040804	112	114	104	23	Ethan	Pasture
5093211	118	115	132	23	Ethan	Pasture
3031407	116	108	145	23	Ethan	Pasture
1302906	121	112	120	24§§	Ethan	Pasture
5173212	131	125	105	13†	Ethan	Small Grain
5173213	115	107	82	13	Ethan	Small Grain

†Clarno-Ethan loams, 2 to 6 percent slopes
§Clarno-Ethan loams, 5 to 9 percent slopes
¶Egan-Ethan complex, 2 to 6 percent slopes
††Ethan-Betts loams, 6 to 15 percent slopes
§§Ethan-Egan complex, 5 to 9 percent slopes
#Film combination
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
3073502	134	118	100	13†	Ethan	Small Grain
3080204	115	116	116	13	Ethan	Small Grain
3101402	136	122	101	13	Ethan	Small Grain
3122315	121	114	120	13	Ethan	Small Grain
3192403	120	106	105	13	Ethan	Small Grain
1243205	115	112	106	13	Ethan	Small Grain
3031312	130	115	97	13	Ethan	Small Grain
3032303	124	124	96	13	Ethan	Small Grain
1090401	133	119	112	13	Ethan	Small Grain
1132102	123	115	99	13	Ethan	Small Grain
1132104	117	108	93	13	Ethan	Small Grain
1142801	115	111	110	13	Ethan	Small Grain
3031308	118	110	101	13	Ethan	Small Grain
1180804	115	106	104	13	Ethan	Small Grain
1180904	131	117	106	13	Ethan	Small Grain
1243305	125	116	110	14§	Ethan	Small Grain
5062007	141	132	118	14	Ethan	Small Grain
5110403	137	125	107	14	Ethan	Small Grain
5110506	157	147	122	14	Ethan	Small Grain
3042402	137	120	113	14	Ethan	Small Grain
1170506	140	125	110	14	Ethan	Small Grain
3153508	149	131	112	14	Ethan	Small Grain
1323208	149	131	110	20¶	Ethan	Small Grain
3261406	126	111	101	20	Ethan	Small Grain
3261412	117	109	115	20	Ethan	Small Grain
3272307	142	123	103	20	Ethan	Small Grain
3282603	130	111	93	20	Ethan	Small Grain
1062905	124	111	102	23††	Ethan	Small Grain
5093201	140	128	104	23	Ethan	Small Grain
3031402	112	103	103	23	Ethan	Small Grain
3091108	114	92	96	23	Ethan	Small Grain
3293502	148	131	101	24§§	Ethan	Small Grain
5062101	136	123	91	24	Ethan	Small Grain
1282102	135	125	119	24	Ethan	Small Grain
1302904	140	123	108	24	Ethan	Small Grain

†Clarno-Ethan loams, 2 to 6 percent slopes
§Clarno-Ethan loams, 5 to 9 percent slopes
¶Egan-Ethan complex, 2 to 6 percent slopes
††Ethan-Betts loams, 6 to 15 percent slopes
§§Ethan-Egan complex, 5 to 9 percent slopes
#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
1201703	93	91	56	28†	Tetonka	Small Grain
5270510	116	113	74	28	Tetonka	Small Grain
5280009	110	105	74	28	Tetonka	Small Grain
5301701	126	116	64	28	Tetonka	Small Grain
5322009	115	111	81	28	Tetonka	Small Grain
5322100	117	114	87	28	Tetonka	Small Grain
5100509	114	111	80	28	Tetonka	Small Grain
5100510	127	121	93	28	Tetonka	Small Grain
5120801	127	117	78	28	Tetonka	Small Grain
3080103	98	89	65	28	Tetonka	Small Grain
3091201	104	94	66	28	Tetonka	Small Grain
3122305	112	104	68	28	Tetonka	Small Grain
3122401	124	113	96	28	Tetonka	Small Grain
3153503	106	98	58	28	Tetonka	Small Grain
3153504	111	97	61	28	Tetonka	Small Grain
3181306	95	89	57	28	Tetonka	Small Grain
3261709	124	111	82	28	Tetonka	Small Grain
5082904	114	111	53	28	Tetonka	Small Grain
1212001	111	108	71	28	Tetonka	Small Grain
1222804	85	80	51	28	Tetonka	Small Grain
5280008	118	112	89	28	Tetonka	Crop Residue
3073601	113	105	81	28	Tetonka	Crop Residue
3080209	120	106	78	28	Tetonka	Crop Residue
3122313	134	121	86	28	Tetonka	Crop Residue
3181405	133	116	85	28	Tetonka	Crop Residue
3212605	133	114	82	28	Tetonka	Crop Residue
1323201	108	107	62	28	Tetonka	Crop Residue
5301702	112	113	82	30§	Worthing	No Cover
5301706	111	109	79	30	Worthing	No Cover
5211401	104	103	70	30	Worthing	No Cover
5322002	111	109	73	30	Worthing	No Cover
5322906	108	106	71	30	Worthing	No Cover
5322801	104	105	77	30	Worthing	No Cover

†Tetonka silt loam
§Worthing silty clay loam
#Film combination
   1 Panchromatic (600-700 nm)
   2 Panchromatic (500-700 nm)
   3 Infrared (700-900 nm

Table 1. Continued.

ID.	Film # 1	2	3	Map Unit	Soil	Land Cover
3042305	93	92	57	30†	Worthing	No Cover
3293501	97	92	54	30	Worthing	No Cover
1222903	94	89	55	30	Worthing	No Cover
1260907	100	97	66	30	Worthing	No Cover
1323301	81	81	44	30	Worthing	No Cover
5322001	144	137	106	30	Worthing	Pasture
3052602	89	84	63	30	Worthing	Pasture
3073501	108	100	91	30	Worthing	Pasture
3080104	101	90	90	30	Worthing	Pasture
3261404	95	94	123	30	Worthing	Pasture
3261410	142	127	115	30	Worthing	Pasture
5051603	96	98	75	30	Worthing	Pasture
1132001	91	92	105	30	Worthing	Pasture
1323207	131	118	96	30	Worthing	Pasture
1323210	108	110	113	30	Worthing	Pasture
3091107	102	94	108	5§	Betts	Pasture
1072802	109	107	120	5	Betts	Pasture
1062909	102	98	122	5	Betts	Pasture
3091113	132	122	122	23¶	Betts	Pasture
3101302	127	116	121	23	Betts	Pasture
3153603	111	104	120	23	Betts	Pasture
3080208	123	108	101	23	Betts	Pasture
5040803	115	120	105	23	Betts	Pasture
5093212	127	120	115	23	Betts	Pasture
3031408	129	118	140	23	Betts	Pasture
3091109	149	121	114	23	Betts	Small Grain
5093202	155	139	107	23	Betts	Small Grain
1062906	142	129	110	23	Betts	Small Grain
5093202	155	139	107	23	Betts	Small Grain

†Worthing silty clay loam
§Betts-Talmo complex, 12 to 40 percent slopes
¶Ethan-Betts loams, 6 to 15 percent slopes
#Film combinations
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

APPENDIX B

STATISTICS BY SOIL AND LAND COVER

APPENDIX B

Table 1. Statistics by cover and soils on undulating landscapes.

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Bare Soil--Bonilla							
1	12	113.0	7.6	98.0	124.0	2.2	6.7
2	12	102.2	7.6	88.0	116.0	2.2	7.4
3	12	72.5	10.4	55.0	86.0	3.00	14.3
Bare Soil--Clarno							
1	41	116.2	10.5	89.0	138.0	1.6	9.0
2	41	105.0	9.7	80.0	126.0	1.5	9.2
3	41	79.5	12.9	57.0	115.0	2.0	16.2
Bare Soil--Ethan							
1	47	130.2	14.2	100.0	164.0	2.1	10.9
2	47	116.9	12.3	88.0	150.0	1.8	10.5
3	47	87.0	11.7	65.0	119.0	1.7	13.4
Bare Soil--Worthing							
1	11	101.6	9.7	81.0	112.0	2.9	9.5
2	11	99.6	10.1	81.0	113.0	3.0	10.1
3	11	66.2	12.1	44.0	82.0	3.7	18.3
Crop Residue--Bonilla							
1	9	131.9	6.0	126.0	142.0	2.0	4.5
2	9	117.8	5.9	112.0	128.0	2.0	5.0
3	9	88.7	8.1	75.0	101.0	2.7	9.1
Crop Residue--Clarno							
1	17	134.1	9.8	114.0	151.0	2.4	7.3
2	17	119.2	8.9	105.0	137.0	2.2	7.5
3	17	88.5	10.4	66.0	105.0	2.5	11.7
Crop Residue--Ethan							
1	10	148.9	14.7	127.0	173.0	4.6	9.9
2	10	130.4	12.9	114.0	153.0	4.1	9.9
3	10	98.7	14.1	74.0	122.0	4.5	14.3
Alfalfa--Clarno							
1	13	83.6	14.5	60.0	112.0	4.0	17.3
2	13	87.2	8.9	73.0	107.0	2.5	10.2
3	13	124.5	17.5	74.0	145.0	4.9	14.1
Alfalfa--Ethan							
1	20	97.1	14.8	72.0	119.0	3.3	15.3
2	20	98.3	10.4	79.0	119.0	2.3	10.6
3	20	125.5	17.3	78.0	173.0	3.9	13.8

†Film combination

1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

APPENDIX B

Table 1 — continued

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Pasture--Clarno							
1	9	109.7	8.7	92.0	121.0	2.9	7.9
2	9	102.8	6.2	92.0	112.0	2.1	6.0
3	9	114.2	17.8	73.0	141.0	5.9	15.5
Pasture--Ethan							
1	17	115.2	9.6	97.0	135.0	2.3	8.3
2	17	108.3	7.4	98.0	121.0	1.8	6.8
3	17	119.2	10.6	104.0	145.0	2.6	8.1
Pasture--Worthing							
1	12	112.0	19.8	89.0	144.0	5.7	17.7
2	12	106.5	16.2	84.0	137.0	4.7	15.2
3	12	98.8	17.4	63.0	123.0	5.0	17.6
Pasture--Betts							
1	10	117.7	11.3	102.0	132.0	3.6	9.6
2	10	110.7	9.9	94.0	122.0	3.1	9.0
3	10	117.4	11.0	101.0	140.0	3.5	9.4
Small Grain--Bonilla							
1	13	114.2	12.1	96.0	135.0	3.3	10.6
2	13	109.2	9.9	95.0	128.0	2.8	9.1
3	13	106.1	8.1	91.0	118.0	2.3	7.7
Small Grain--Clarno							
1	31	116.9	12.2	91.0	139.0	2.2	10.4
2	31	110.2	9.6	95.0	131.0	1.7	8.7
3	31	103.6	10.2	81.0	121.0	1.8	9.8
Small Grain--Ethan							
1	38	129.2	11.5	112.0	157.0	1.9	8.9
2	38	117.6	10.1	92.0	147.0	1.6	8.6
3	38	105.2	8.9	82.0	122.0	1.5	8.5
Small Grain--Betts							
1	4	145.0	9.1	134.0	155.0	4.5	6.3
2	4	127.3	8.8	120.0	139.0	4.4	6.9
3	4	112.0	4.4	107.0	117.0	2.2	3.9

†Film combination

1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

APPENDIX B

Table 2. Statistics by cover and soils on nearly level landscapes.

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Bare Soil--Bonilla							
1	27	110.9	8.1	85.0	125.0	1.6	7.3
2	27	103.1	7.3	79.0	116.0	1.4	7.1
3	27	71.4	8.3	54.0	92.0	1.6	7.1
Bare Soil--Clarno							
1	35	114.6	8.4	90.0	129.0	1.4	7.3
2	35	105.3	6.8	83.0	120.0	1.1	6.4
3	35	73.9	8.3	56.0	90.0	1.4	11.3
Bare Soil--Crossplain							
1	13	107.2	9.1	89.0	121.0	2.5	8.5
2	13	99.8	6.7	89.0	113.0	1.9	6.7
3	13	69.5	12.8	56.0	108.0	3.5	18.4
Bare Soil--Davison							
1	8	119.5	9.5	108.0	134.0	3.4	8.0
2	8	108.9	5.1	102.0	117.0	1.8	4.7
3	8	78.1	5.5	69.0	85.0	1.9	7.0
Bare Soil--Tetonka							
1	21	110.5	12.3	85.0	127.0	2.7	11.1
2	21	104.1	11.3	80.0	121.0	2.5	10.9
3	21	70.1	13.1	51.0	96.0	2.9	18.7
Bare Soil--Worthing							
1	11	101.6	9.7	81.0	112.0	2.9	9.5
2	11	99.6	10.1	81.0	113.0	3.0	10.1
3	11	66.2	12.1	44.0	82.0	3.7	18.3
Alfalfa--Bonilla							
1	9	70.0	14.2	43.0	93.0	4.7	20.3
2	9	85.3	12.3	70.0	108.0	4.1	14.4
3	9	138.1	16.1	116.0	172.0	5.4	11.7
Alfalfa--Clarno							
1	16	76.9	9.9	56.0	100.0	2.5	12.9
2	16	88.7	9.3	80.0	115.0	2.3	10.5
3	16	130.7	10.6	113.0	148.0	2.7	8.1
Alfalfa--Crossplain							
1	8	69.7	3.5	66.0	77.0	1.2	5.0
2	8	83.3	1.6	80.0	85.0	0.6	1.9
3	8	138.6	10.0	126.0	151.0	3.6	7.2

†Film combination

1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

APPENDIX B

Table 2 — continued

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Alfalfa--Davison							
1	10	84.0	8.3	74.0	102.0	2.6	9.8
2	10	90.4	5.0	87.0	104.0	1.6	5.6
3	10	128.6	6.4	118.0	141.0	2.0	4.9

†Film combination

1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

APPENDIX B

Table 3. Statistics by cover of Clarno and Bonilla soils on all landscapes.

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Bare Soil--Bonilla							
1	39	111.5	7.9	85.0	125.0	1.3	7.1
2	39	102.8	7.3	79.0	116.0	1.2	7.1
3	39	71.8	8.9	54.0	92.0	1.4	12.4
Bare Soil--Clarno							
1	39	116.7	8.0	90.0	132.0	1.3	6.9
2	39	106.1	7.0	83.0	120.0	1.1	6.6
3	39	75.6	10.5	56.0	107.0	1.7	13.9
Crop Residue--Bonilla							
1	17	129.0	8.3	104.0	142.0	2.0	6.4
2	17	117.1	5.4	109.0	128.0	1.3	4.6
3	17	87.3	7.5	75.0	101.0	1.8	8.5
Crop Residue--Clarno							
1	17	134.9	7.2	117.0	149.0	1.8	5.3
2	17	121.1	5.3	111.0	131.0	1.3	4.4
3	17	89.9	7.7	76.0	104.0	1.9	8.6
Alfalfa--Bonilla							
1	10	70.2	13.4	43.0	93.0	4.2	19.1
2	10	84.8	11.7	70.0	108.0	3.7	13.8
3	10	139.2	15.6	116.0	172.0	4.9	11.2
Alfalfa--Clarno							
1	10	76.4	12.5	56.0	100.0	3.9	16.3
2	10	89.9	11.8	80.0	115.0	3.7	13.1
3	10	131.3	12.1	113.0	148.0	3.8	9.2
Small Grain--Bonilla							
1	32	115.7	12.4	89.0	135.0	2.2	10.7
2	32	111.1	8.6	95.0	128.0	1.5	7.8
3	32	105.1	9.3	94.0	124.0	1.6	8.8
Small Grain--Clarno							
1	30	121.0	11.3	101.0	139.0	2.1	9.3
2	30	114.4	9.3	97.0	131.0	1.7	8.1
3	30	107.1	10.3	83.0	128.0	1.9	9.6

†Film combination

1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

APPENDIX B

Table 4. Statistics by cover of Clarno and Ethan soils on undulating landscapes.

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Bare Soil--Clarno							
1	29	115.3	11.5	89.0	138.0	2.1	10.0
2	29	104.8	10.7	80.0	126.0	2.0	10.3
3	29	80.3	12.7	57.0	115.0	2.4	15.8
Bare Soil--Ethan							
1	35	132.6	14.5	100.0	164.0	2.5	11.0
2	35	118.9	12.9	88.0	150.0	2.2	10.9
3	35	89.3	11.9	65.0	119.0	2.0	13.4
Crop Residue--Clarno							
1	8	130.4	12.1	114.0	151.0	4.3	9.3
2	8	116.4	11.3	105.0	137.0	4.0	9.7
3	8	84.8	11.8	66.0	105.0	4.2	13.9
Crop Residue--Ethan							
1	9	147.6	14.9	127.0	173.0	5.0	10.1
2	9	129.7	13.5	114.0	153.0	4.5	10.4
3	9	97.4	14.4	74.0	122.0	4.8	14.7
Alfalfa--Clarno							
1	12	84.3	14.9	60.0	112.0	4.3	17.7
2	12	87.3	9.3	73.0	107.0	2.7	10.6
3	12	123.3	17.7	74.0	145.0	5.1	14.3
Alfalfa--Ethan							
1	14	96.9	16.9	72.0	119.0	4.5	17.4
2	14	97.3	12.1	79.0	119.0	3.2	12.4
3	14	125.9	20.9	78.0	173.0	5.6	16.6
Pasture--Clarno							
1	7	108.3	9.4	92.0	121.0	3.5	8.7
2	7	102.1	6.6	92.0	112.0	2.5	6.5
3	7	119.9	10.0	112.0	141.0	3.8	8.3
Pasture--Ethan							
1	11	114.1	11.0	97.0	135.0	3.3	9.6
2	11	106.6	8.0	98.0	121.0	2.4	7.5
3	11	116.0	7.4	109.0	135.0	2.2	6 4
Small Grain--Clarno							
1	18	115.4	12.1	91.0	136.0	2.9	10.5
2	18	108.5	8.3	95.0	124.0	2.0	7.6
3	18	100.1	10.5	109.0	116.0	2.5	10.5
Small Grain--Ethan							
1	24	128.0	11.1	115.0	157.0	2.3	8.7
2	24	118.3	9.4	106.0	147.0	1.9	8.0
3	24	106.4	9.5	82.0	122.0	1.9	8.9

†Film combination
1 Panchromatic (600-700 nm)
2 Panchromatic (500-700 nm)
3 Infrared (700-900 nm)

APPENDIX B

Table 5. Statistics by cover of Clarno, Crossplain and Davison soils on nearly level landscapes.

Film†	N	Mean	Standard deviation	Minimum value	Maximum value	Std. error of mean	C.V.
Bare Soil--Clarno							
1	8	110.1	7.5	100.0	119.0	2.7	6.8
2	8	101.9	3.3	97.0	106.0	1.2	3.3
3	8	70.9	5.5	62.0	80.0	1.9	7.7
Bare Soil--Crossplain							
1	8	105.9	10.0	89.0	121.0	3.5	9.4
2	8	98.9	5.2	92.0	107.0	1.9	5.3
3	8	68.5	4.8	64.0	76.0	1.7	7.0
Bare Soil--Davison							
1	8	119.5	9.5	108.0	134.0	3.4	8.0
2	8	108.9	5.1	102.0	117.0	1.8	4.7
3	8	78.1	5.5	69.0	85.0	1.9	7.0
Alfalfa--Clarno							
1	7	77.6	3.6	73.0	83.0	1.4	4.6
2	7	86.6	1.4	84.0	88.0	0.5	1.6
3	7	131.1	8.8	116.0	140.0	3.3	6.7
Alfalfa--Crossplain							
1	8	69.8	3.5	66.0	77.0	1.2	5.0
2	8	83.3	1.6	80.0	85.0	0.6	1.9
3	8	138.6	10.0	126.0	151.0	3.6	7.2
Alfalfa--Davison							
1	10	84.9	8.3	74.0	102.0	2.6	9.8
2	10	90.4	5.0	87.0	104.0	1.6	5.6
3	10	128.6	6.4	118.0	141.0	2.0	4.9

†Film combination

1 Panchromatic (600–700 nm)
2 Panchromatic (500–700 nm)
3 Infrared (700–900 nm)

APPENDIX C

AN EXAMPLE OF THE SAS STEPDISC PROGRAM FOR CLARNO AND ETHAN SOILS ON UNDULATING LANDSCAPES

APPENDIX C

An example of the SAS STEPDISC program for Clarno and Ethan soils on undulating landscapes follows:

```
DATA TRANS;

  INPUT ID V1 V2 V3 SOI_NO@@ COV_NO@@;
    IF SOI_NO@@=7 THEN SOIL='CLARNO';
      ELSE IF =OI_NO@@=15 THEN SOIL='ETHAN';
    IF COV_NO@@=1 THEN COVER='NO COVER';
      ELSE IF COV_NO@@=2 THEN COVER='CROP RES';
      ELSE IF COV_NO@@=3 THEN COVER='ALFALFA';
      ELSE IF COV_NO@@=4 THEN COVER='PASTURE';
      ELSE IF COV_NO@@=5 THEN COVER='SM GRAIN';
    CARDS;
                              (data lines)
;
PROC SORT;
BY COVER;
PROC STEPDISC STEPWISE SIMPLE STDMEAN TCOOR WCORR;
CLASSES SOIL;
VAR V1 V2 V3;
BY COVER;
```

The STEPDISC subroutine calculates and/or prints the following:

1. Frequency of each soil, and the proportion in the total sample.
2. Soil class means.
3. Standard deviations, both for the total sample and the pooled within class matrix.
4. Within-standardized soil class means, obtained by subtracting the grand mean from each soil class mean and dividing by the pooled within-class standard deviation.
5. Total-standardized soil class means obtained by subtracting the grand mean from each soil class mean and dividing by the total sample standard deviation.

6. Total sample correlations.

7. Pooled within-class correlations.

At each step the following statistics are calculated and printed:

8. For each film variable considered for entry or removal: partial r^2, the squared partial correlation, the F statistics, and probability > F, the probability level, from a one-way analysis of covariance.

9. The tolerance for each variable film considered for entry which is one minus the squared multiple correlation of the film variables already in the model.

10. The name of the film variable chosen.

11. The film variable(s) already selected or removed.

12. Wilks' lambda and the associated F approximation with degrees of freedom and probability > F, the associated probability level after the selected film variable has been entered or removed. Wilks' lambda is close to 0 if any two groups are well separated.

13. Average squared cononical correlation, calculated as Pillai's trace divided by the number of groups minus 1. Average squared cononical correlation is close to 1 if all groups are well separated in the discriminant space for at least two groups.

An example of the output of the STEPDISC subroutine for Clarno and Ethan soils on undulating landscapes with no land cover follows:

Clarno and Ethan Soils on Undulating Landscapes
Cover=No Cover

Stepwise Discriminant Analysis

64 observations 3 variable(s) in the analysis
2 class levels 0 variable(s) will be included

The Method(s) for Selecting Variables Will be STEPWISE

Significance Level to Enter = 0.1500
Significance Level to Stay = 0.0500

Class Level Information

Soil	Frequency	Proportion
Clarno	29	0.45312500
Ethan	35	0.54687500

Class Means

Variable	Clarno	Ethan
V1	1115.2759	132.6286
V2	104.8276	118.9429
V3	80.3103	89.2571

Standard Deviations

Variable	Total Sample	Within Class
V1	15.76891	13.25310
V2	13.83225	11.97714
V3	12.98739	12.28485

Within-Standardized Class Means

Variable	Clarno	Ethan
V1	-.716041	0.593291
V2	-.644502	0.534016
V3	-.398277	0.330001

Total-Standardized Class Means

Variable	Clarno	Ethan
V1	-.601802	0.498636
V2	-.558065	0.462396
V3	-.376733	0.312150

Total Sample Correlations

	V1	V2	V3
V1	1.0000	0.9102	0.5114
V2	0.9102	1.0000	0.5664
V3	0.5114	0.5664	1.0000

Pooled Within Class Correlations

	V1	V2	V3
V1	1.0000	0.8761	0.4097
V2	0.8761	1.0000	0.4831
V3	0.4097	0.4831	1.0000

STEPWISE Selection Step 1

Statistics for Entry, DF = 1,62

Variable	R**2	F	Prob > F	Tolerance
V1	0.3048	27.189	0.0001	1.0000
V2	0.2621	22.027	0.0001	1.0000
V3	0.1195	8.412	0.0052	1.0000

Variable V1 Will be Entered

The Following Variable(s) Have Been Entered
V1

Multivariate Statistics

Wilks' Lambda =	0.69515658	F(1,62) =	27.189	PROB > F=0.0000
Pillai's Trace =	0.304843	F(1,62) =	27.189	PROB > F=0.0000

Average Squared Canonical Correlation = 0.30484342

STEPWISE Selection Step 2

Statistics for Removal, DF = 1,62

Variable	R**2	F	Prob > F
V1	0.3048	27.189	0.0001

No Variables Can Be Removed

Statistics for Entry, DF = 1,61

	Partial R**2	F	Prob > F	Tolerance
V2	0.0008	0.046	0.8311	0.1716
V3	0.0078	0.480	0.4912	0.7385

No Variables Can Be Entered

No Further Steps are Possible

Stepwise Selection Summary

Step	Variable Entered	Variable Removed	Number In	Partial R**2	F Statistic	Prob > F
1	V1		1	0.3048	27.189	0.0001

Wilks' Lambda	Prob > Lambda	Average Squared Canonical Correlation	Prob > ASCC
0.69515658	0.0000	0.30484342	0.0000

APPENDIX D

AN EXAMPLE OF THE SAS DISCRIM PROGRAM FOR CLARNO AND ETHAN SOILS ON UNDULATING LANDSCAPES WITH NO LAND COVER

APPENDIX D

The DATA statements of the DISCRIM subroutine is similar to that of the STEPDISC subroutine. The PROC statements for Clarno and Ethan soils on undulating landscapes with no land cover using the panchromatic (600–700 nm) film follow:

```
PROC SORT;
  BY COVER:
PROC DISRIM WCORR PCORR LIST POOL = TEST SPOOL = .05;
  CLASSES SOIL;
  VAR V1;
  PRIORS PROP;
  BY COVER;
```

The DISCRIM subroutine calculates and prints the following:

1. Frequencies and prior probabilities for each soil group. Proportional prior probabilities were used in this program.
2. Within correlation coefficients and probability > |R| (the within-group correlation matrix for each group).
3. Partial correlation coefficients computed from the pooled covariance matrix and probability > |R| (The partial correlation matrix based on the pooled covariance matrix).
4. Within covariance matrix information including covariance matrix rank and natural log of determinant of the covariance matrix for each group.
5. Test of homogeneity of within covariance matrices (the results of a chi-square test of homogeneity of the within-group covariance matrices).
6. The pairwise squared generalized differences between soil groups.
7. If the pooled covariance matrix is used, the linearized discriminant function.

8. The classification results including the observation number, the actual soil group for the observation, the soil group into which the discriminant model would classify it, and the posterior probability of its membership in each soil group.
9. Classification summary of the performance of the discriminant model.

An example of the output of the DISCRIM subroutine for Clarno and Ethan soils on undulating landscapes with no land cover using the panchromatic (600-700 nm) film follows:

Clarno and Ethan Soils on Undulating Landscapes

Class Level Information

Soil	Frequency	Prior Probability
Clarno	29	0.45312500
Ethan	35	0.54687500
Total	64	1.00000000

Within Correlation Coefficients/Probability R

Soil=Clarno

Variable	V1
V1	1.000000 0.0000

Soil=Ethan

Variable	V1
V1	1.000000 0.0000

Partial Correlation Coefficients Computed From Pooled Covariance Matrix/Prob R

Variable	V1
V1	1.000000 0.0000

Within Covariance Matrix Information

Soil	Covariance Matrix Rank	Natural Log of Determinant of the Covariance Matrix
Clarno	1	4.88382767
Ethan	1	5.35410977
Pooled	1	5.16846257

Test of Homogeneity of Within Covariance Matrices

Notation
- I = Number of Groups
- P = Number of Variables
- N = Total Number of Observations
- N(I) = Number of Observations in the I'th Group

$$V = \frac{\left|\text{Within SS Matrix(I)}\right|^{N(I)/2}}{\left|\text{Pooled SS Matrix}\right|^{N/2}}$$

$$RHO = 1.0 - \left[SUM \frac{1}{N(I)-1} - \frac{1}{N-K} \right] \frac{2P^2 + 3P - 1}{6(P+1)(K-1)}$$

$$DF = .5(K-1)P(P+1)$$

Under Null Hypothesis $-2\ RHO\ LN \left[\frac{N^{PN/2}\ V}{N(I)^{PN(I)/2}} \right]$ is distributed approximately as Chi-square(DF)

Test Chi-Square Value = 1.72835898 with 1 DF Prob > Chi-Sq = 0.1886

Since the Chi-Square value is not significant at 0.05 level, a pooled covariance matrix will be used in the discriminant function.

Pairwise Squared Generalized Distances Between Groups

$$D^2(I\ J) = (X_I - X_J)'\ COV^{-1}\ (X_I - X_J) - 2\ LN\ PRIOR$$

Generalized Squared Distance to Soil

From Soil	Clarno	Ethan
Clarno	1.58317451	2.92142130
Ethan	3.29752576	1.20707004

Linearized Discriminant Function

$$CONSTANT = -.5\ X'_J\ COV^{-1}\ X_J + LN\ PRIOR_J \qquad COEFFICIENT\ VECTOR = COV^{-1}\ X_J$$

Soil

Constant	Clarno	Ethan
V1	-38.61946580	-50.67720378
	0.65630181	0.75509625

Classification Results for Calibration Data

Generalized Squared Distance Function

$$D_J^2(X) = (X-X_J)'\ COV^{-1}\ (X-X_J) - 2\ LN\ PRIOR_J$$

Posterior Probability of Membership in Each Soil

$$PR(J\ XX) = EXP(-.5\ D_J^2(X))\ /\ SUM_K\ EXP(-.5\ D_K^2(X))$$

OBS	FROM SOIL	CLASSIFIED INTO SOIL	CLARNO	ETHAN
1	Clarno	15*	0.3801	0.6199
2	Clarno	15*	0.2176	0.7824
3	Clarno	7	0.5012	0.4988
4	Clarno	7	0.9291	0.0709
5	Clarno	7	0.7097	0.2903
6	Clarno	7	0.6451	0.3549

Classification Results for Calibration Data

Posterior Probability of Membership in Soil

OBS	FROM SOIL	CLASSIFIED INTO SOIL	CLARNO	ETHAN
7	Clarno	7	0.7840	0.2160
8	Clarno	7	0.6889	0.3111
9	Clarno	7	0.6451	0.3549
10	Clarno	7	0.7097	0.2903
11	Clarno	7	0.8156	0.1844
12	Clarno	7	0.6451	0.3549
13	Clarno	7	0.7840	0.2160
14	Clarno	7	0.7668	0.2332
15	Clarno	15*	0.3801	0.6199
16	Clarno	7	0.8788	0.1212
17	Clarno	7	0.6451	0.3549
18	Clarno	7	0.6451	0.3549
19	Clarno	7	0.9070	0.0930
20	Clarno	7	0.9632	0.0368
21	Clarno	15*	0.3801	0.6199
22	Clarno	15*	0.4276	0.5724
23	Clarno	7	0.7840	0.2160
24	Clarno	7	0.8561	0.1439
25	Clarno	7	0.6889	0.3111
26	Clarno	15*	0.2531	0.7469
27	Clarno	15*	0.1714	0.8286
28	Clarno	15*	0.4765	0.5235
29	Clarno	7	0.5987	0.4013
30	Ethan	15	0.2531	0.7469
31	Ethan	15	0.4036	0.5964
32	Ethan	15	0.0939	0.9061
33	Ethan	7*	0.5504	0.4496
34	Ethan	7*	0.8983	0.1017
35	Ethan	7*	0.5259	0.4741
36	Ethan	15	0.2923	0.7077
37	Ethan	15	0.3571	0.6429
38	Ethan	7*	0.5504	0.4496
39	Ethan	15	0.2531	0.7469
40	Ethan	7*	0.8300	0.1700
41	Ethan	15	0.1333	0.8667
42	Ethan	15	0.0594	0.9406
43	Ethan	15	0.1026	0.8974
44	Ethan	7	0.5747	0.4253
45	Ethan	15	0.0858	0.9142
46	Ethan	15	0.3801	0.6199
47	Ethan	15	0.0156	0.9844
48	Ethan	15	0.0715	0.9285
49	Ethan	15	0.1578	0.8422
50	Ethan	15	0.0172	0.9828

Classification Results for Calibration Data

Posterior Probability of Membership in Soil

OBS	FROM SOIL	CLASSIFIED INTO SOIL	CLARNO	ETHAN
51	Ethan	15	0.3801	0.6199
52	Ethan	15	0.2013	0.7987
53	Ethan	15	0.4276	0.5724
54	Ethan	7*	0.5747	0.4253
55	Ethan	15	0.0715	0.9285
56	Ethan	15	0.2349	0.7651
57	Ethan	15	0.3801	0.6199
58	Ethan	7*	0.6889	0.3111
59	Ethan	15	0.3348	0.6652
60	Ethan	15	0.2531	0.7469
61	Ethan	15	0.0783	0.9217
62	Ethan	15	0.3348	0.6652
63	Ethan	15	0.0542	0.9458
64	Ethan	7*	0.5747	0.4253

*Misclassified observation

Classification Summary for Calibration Data

Generalized Squared Distance Function

$$D_J^2(X) = (X-X_J)'\ COV^{-1}\ (x-X_J) - 2\ LN\ PRIOR_J$$

Posterior Probability of Membership in Each Soil

$$PR(J\ X) = EXP(-.5\ D_J^2(X))\ /\ SUM_K\ EXP(-.5\ D_K^2(X))$$

Number of Observations and Percents Classified Into Soil

From Soil	Clarno	Ethan	Total
Clarno	21	8	29
	72.41	27.59	100.00
Ethan	9	26	64
	25.71	74.29	100.00
Total	30	34	64
Percent	46.88	53.13	100.00
Priors	0.4531	0.5469	
Overall Percent	73		

APPENDIX E

DISCRIMINANT CLASSIFICATION OF SOILS BY LAND COVER AND FILM

Table 1. Discriminant classification of soils on undulating landscapes with no land cover.

Table 1a. Panchromatic (600-700 nm) film.

	Number of observations/percent classified into soil				
Soil	Bonilla	Clarno	Ethan	Worthing	Total
Bonilla	0	10	1	1	12
	0	83	8	8	
Clarno	0	29	9	3	41
	0	71	22	7	
Ethan	0	15	32	0	47
	0	32	69	0	
Worthing	0	7	0	4	11
	0	64	0	36	

Over-all Accuracy = 59%

Table 1b. Panchromatic (600-700) nm and panchromatic (500-700 nm) films.

	Number of observations/percent classified into soil				
Soil	Bonilla	Clarno	Ethan	Worthing	Total
Bonilla	0	11	1	0	12
	0	92	8	0	
Clarno	0	28	9	4	41
	0	68	22	10	
Ethan	0	13	32	2	47
	0	28	68	4	
Worthing	0	0	0	11	11
	0	0	0	100	

Over-all Accuracy = 64%

Table 1c. Panchromatic (600-700 nm), panchromatic (500-700 nm), and infrared (700-900 nm) films.

	Number of observations/percent classified into soil				
Soil	Bonilla	Clarno	Ethan	Worthing	Total
Bonilla	3 25	8 67	1 8	0 0	12
Clarno	6 15	25 61	9 22	1 2	41
Ethan	3 6	11 23	33 70	0 0	47
Worthing	0 0	0 0	0 0	11 100	11

Over-all Accuracy = 65%

Table 2. Discriminant classification of soils on nearly level landscapes with no land cover.

Table 2a. Panchromatic (600-700 nm) film.

	Number of observations/percent classified into soil						
Soil	Bonilla	Clarno	Crossplain	Davison	Tetonka	Worthing	Total
Bonilla	5 19	21 78	0 0	0 0	0 0	1 4	27
Clarno	3 9	31 89	0 0	0 0	0 0	1 3	35
Crossplain	2 15	8 62	0 0	0 0	0 0	3 23	13
Davison	0 0	8 100	0 0	0 0	0 0	0 0	8
Tetonka	3 14	14 67	0 0	0 0	0 0	4 19	21
Worthing	3 27	4 36	0 0	0 0	0 0	4 36	11

Over-all Accuracy = 31%

Table 2b. Panchromatic (600–700 nm) and panchromatic (500–700 nm) films.

	Number of observations/percent classified into soil						
Soil	Bonilla	Clarno	Crossplain	Davison	Tetonka	Worthing	Total
Bonilla	9	15	0	0	2	1	27
	33	56	0	0	7	4	
Clarno	6	23	0	0	3	3	35
	17	66	0	0	9	9	
Crossplain	3	6	1	0	2	1	13
	23	46	8	0	15	8	
Davison	2	4	0	2	0	0	8
	25	50	0	25	0	0	
Tetonka	4	8	1	0	6	2	21
	19	38	5	0	29	10	
Worthing	1	0	0	0	1	9	11
	9	0	0	0	9	82	

Over-all Accuracy = 44%

Table 3. Discriminant classification of Clarno and Bonilla soils on nearly level and undulating landscapes covered with crop residue using panchromatic (600-700 nm) film.

Number of observations/percent classified into soil			
Soil	Bonilla	Clarno	Total
Bonilla	11 65	6 35	17
Clarno	5 29	12 71	17

Over-all Accuracy = 68%

Table 4. Discriminant classification of Clarno and Ethan soils on undulating landscapes with growing small grain using panchromatic (600-700 nm) film.

Number of observations/percent classified into soil			
Soil	Clarno	Ethan	Total
Clarno	12 67	6 33	18
Ethan	7 29	17 71	24

Over-all Accuracy = 69%

Table 5. Discriminant classification of Clarno, Crossplain and Davison soils on nearly level landscapes with no land cover using panchromatic (500-700 nm) film.

	Number of observations/percent classified into soil			
Soil	Clarno	Crossplain	Davison	Total
Clarno	3 38	4 50	1 13	8
Crossplain	3 38	4 50	1 13	8
Davison	3 38	0 0	5 63	8

Over-all Accuracy = 50%

Table 6. Discriminant classification of soils on undulating landscapes covered with crop residue.

Table 6a. Panchromatic (600-700 nm) film.

	Number of observations/percent classified into soil			
Soil	Bonilla	Clarno	Ethan	Total
Bonilla	0 0	9 100	0 0	9
Clarno	0 0	15 88	2 12	17
Ethan	0 0	5 50	5 50	10

Over-all Accuracy = 56%

Table 6b. Panchromatic (600-700 nm) and infrared (700-900 nm) films.

Soil	Bonilla	Clarno	Ethan	Total
	Number of observations/percent classified into soil			
Bonilla	3 33	6 67	0 0	9
Clarno	2 12	15 88	0 0	17
Ethan	0 0	3 30	7 70	10

Over-all Accuracy = 69%

Table 7. Discriminant classification of Clarno and Ethan soils on undulating landscapes with no land cover using panchromatic (600-700 nm) film.

Soil	Clarno	Ethan	Total
	Number of observations/percent classified into soil		
Clarno	21 72	8 28	29
Ethan	9 26	26 74	35

Over-all Accuracy = 73%

Table 8. Discriminant classification of soils on undulating landscapes with growing alfalfa using panchromatic (500-700 nm) film.

	Number of observations/percent classified into soil		
Soil	Bonilla	Ethan	Total
Bonilla	9 69	4 31	13
Ethan	4 20	16 80	20

Over-all Accuracy = 75%

Table 9. Discriminant classification of soils on nearly level landscapes with growing alfalfa using panchromatic (600-700 nm) film.

	Number of observations/percent classified into soil				
Soil	Bonilla	Clarno	Crossplain	Davison	Total
Bonilla	1 11	1 11	5 56	2 22	9
Clarno	1 6	11 69	2 13	2 13	16
Crossplain	0 0	1 13	7 88	0 0	8
Davison	0 0	7 70	0 0	3 30	10

Over-all Accuracy = 51%

Table 10. Discriminant classification of soils on undulating landscapes in pasture using infrared (700–900 nm) film.

	Number of observations/percent classified into soil				
Soil	Clarno	Ethan	Worthing	Betts	Total
Clarno	0 0	8 89	1 11	0 0	9
Ethan	0 0	16 94	1 6	0 0	17
Worthing	0 0	5 42	7 58	0 0	12
Betts	0 0	8 80	2 20	0 0	10

Over-all Accuracy = 48%

Table 11. Discriminant classification of Clarno and Bonilla soils on nearly level and undulating landscapes with no land cover using panchromatic (600–700 nm) film.

	Number of observations/percent classified into soil		
Soil	Bonilla	Clarno	Total
Bonilla	28 72	11 28	39
Clarno	13 33	26 67	39

Over-all Accuracy = 72%

Table 12. Discriminant classification of Clarno and Ethan soils on undulating landscapes covered with crop residue.

	Number of observations/percent classified into soil		
Soil	Clarno	Ethan	Total
Clarno	6 75	2 25	8
Ethan	3 33	6 67	9

Over-all Accuracy = 71%

Table 11b. Panchromatic (600–700 nm) film.

	Number of observations/percent classified into soil		
Soil	Clarno	Ethan	Total
Clarno	6 75	2 25	8
Ethan	1 11	8 89	95

Over-all Accuracy = 82%

Table 13. Discriminant classification of Clarno, Crossplain and Davison soils on nearly level landscapes with growing alfalfa using panchromatic (600–700 nm) film.

	Number of observations/percent classified into soil			
Soil	Clarno	Crossplain	Davison	Total
Clarno	5 71	1 14	1 14	7
Crossplain	1 13	7 88	0 0	8
Davison	4 40	0 0	6 60	10

Over-all Accuracy = 72%

Table 14. Discriminant classification of soils on undulating landscapes with growing small grain using panchromatic (600–700 nm) film.

	Number of observations/percent classified into soil				
Soil	Bonilla	Clarno	Ethan	Betts	Total
Bonilla	0 0	9 69	4 31	0 0	13
Clarno	0 0	19 61	12 39	0 0	31
Ethan	0 0	11 29	26 68	1 3	38
Bets	0 0	0 0	4 100	0 0	4

Over-all Accuracy = 52%

Table 15. Discriminant classification of Clarno, and Ethan soils on undulating landscapes with growing alfalfa using panchromatic (500–700 nm) film.

	Number of observations/percent classified into soil		
Soil	Clarno	Ethan	Total
Clarno	8 67	4 33	12
Ethan	5 36	9 64	14

Over-all Accuracy = 65%

Panchromatic, Infrared, and Color-Infrared

Photography for Soil Survey

ABSTRACT

Efforts have been underway in the soil survey program to increase mapping speed while not sacrificing map quality. Four types of aerial photography were tested to determine which type or types of photography were most useful in distinguishing soil differences in complex mapping units on a variety of land cover types.

The color-infrared photography was most useful in recognizing and identifying tonal differences among soil series within mapped areas with no land cover, crop residue, and growing small grain. In areas where alfalfa or pasture covered the soil surface, color-infrared or panchromatic were similar in ease of recognition of tonal differences among soil series within mapping unit complexes.

INTRODUCTION AND LITERATURE REVIEW

Soil series present within mapping unit complexes are inferred from tonal differences on aerial photographs. Visual contrast available in color photography is considerably greater than that in panchromatic photography (Evans, 1948).

The spectral signature of a landscape depends on the combined spectral properties of the soil and plant cover present. Spectral signatures of unvegetated landscapes are a function of soil color, organic matter content, mineralogical composition, surface texture and moisture content (Bowers and Hanks, 1965). Reflectance from vegetated landscapes is a function of leaf structure, shape, size, and orientation; crop species, variety, maturity, and geometric configuration; crop vigor: soil and plant moisture content; chlorophyll content; canopy cover; and background soil reflectance (Gates, et al., 1965).

Benson (1973) compared panchromatic, black and white infrared, and color infrared film to determine the best spectral range for detecting soil limitation in unvegetated and spring wheat fields. The color-infrared film was found to be the most useful film in the detection of natric soils, erosion, and wetness limitations.

Frazee et al., 1972, used panchromatic, black and white, infrared, and color infrared photography to determine their usefulness in making and updating soil and range surveys. General soil patterns were displayed on the panchromatic and color-infrared photography. The black and white infrared film had little contrast except for drainageways and depressions that had more actively growing vegetation. For rangeland soil mapping, the color infrared film correlated more closely with actual soil boundaries than the panchromatic or black and white infrared films.

The objective of this study was to determine which type of photography is most effective in distinguishing soil differences between soil series components of complex mapping units in a cropland area with several types of land cover.

MATERIALS AND METHODS

Data Collection

Panchromatic (500-700 nm), panchromatic (600-700 nm), black and white infrared (700-900 nm), and color infrared (500-900 nm) photography were collected on May 11, 1976 from an area of Turner County, South Dakota. A plane, equipped with four matched 70 mm Hasselblad cameras[1] with a 15.24 cm focal length, was flown at an altitude of about 3033 meters. Prints at a scale of 1:20,000 were made from the negatives for field use.

The panchromatic (600-700 nm) was obtained using Kodak Plus-X Aerographic (2402) film with a Wratten 25A (red) filter[1] to record dominately orange and red wavelengths (Eastman Kodak Company, 1970, and Eastman Kodak Company, 1972). The panchromatic (500-700 nm) was obtained using Kodak Plus-X Aerographic (2402) film with Wratten HF3 and HF4 (haze) filters[1] to record dominately the green, yellow, orange, and red part of the electromagnetic spectrum. Kodak Infrared Aerographic 2424 film with a Wratten 89B (deep red) filter[1] was used to represent only the near-infrared (700-900 nm) portion of the spectrum. Color infrared (500-900 nm) was obtained using Kodak Aerochrome Infrared (2443) film with a Wratten 15 (yellow) and CC30M (magenta) filters[1]. Green objects appear blue, red objects appear green, and infrared reflectances appear red in color infrared photographs (Fritz, 1967).

The four types of photographs were visually evaluated for ease of recognition and identification of tonal differences between soil series within mapping unit complexes over the dominant landcover types in the study area.

---

[1]Product names are given as information and do not represent an endorsement by SDSU or the USDA-SCS.

Study Area

The 621 km^2 test area is situated between 43° 05'N, 97° 00'W and 43° 30'N, 97° 25'W in Turner County, South Dakota, U.S.A. (Figure 1). Soil parent materials of the area are late Wisconsin age glacial till (Flint, 1955).

The dominant soil series of the area were Mollisols (Table 1) (Soil Survey Staff, 1975 and Soil Survey Staff, 1982). Soil characteristics affecting reflection of the soil series in the study area were color, organic matter content, drainage class, landscape position, and texture (Table 2) (Kunze, 1982).

Ground Truth

Ground truth was collected on May 14, 1976 from a transect through the study area by F. C. Westin, South Dakota State University and D. M. Heil, Soil Conservation Service.

At the time that photography was collected, many fields had no land cover due to field preparation for planting. Both fall and spring seedbed tillage operations were common in the study areas. Moisture content of the surface varied due to the time of the last tillage and the soil characteristics.

Some fields were covered by crop residue from the previous crop year. The residue consisted mostly of corn (*Zea mays*), soybean (*Glycine max*), or small grain residue.

Alfalfa (*Medicago sativa*) was growing vigorously on the day the photography was flown. The alfalfa ranged from 15 to 20 cm in height.

Figure 1. Location of the Study Area

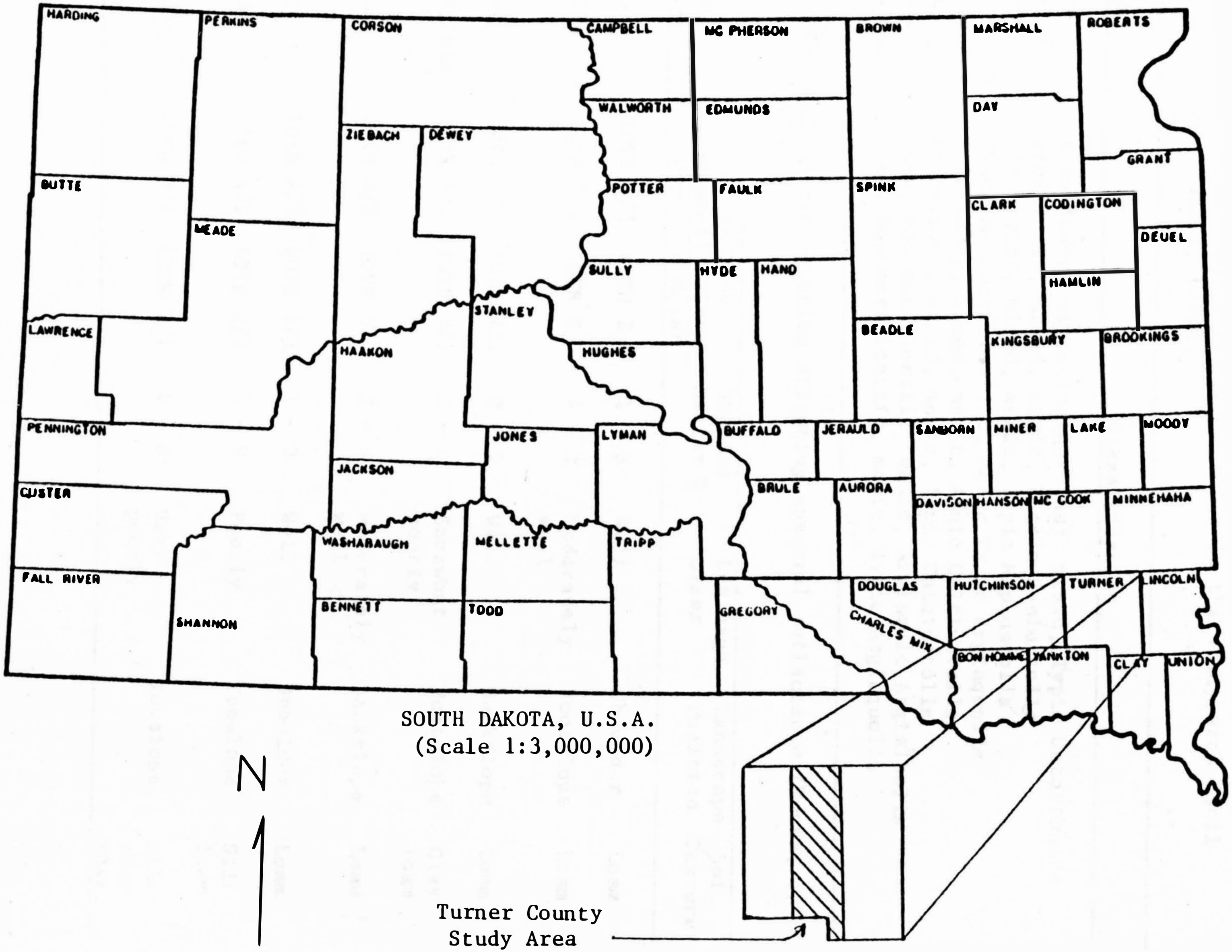


Table 1. Classification of the major soils in the study area (Soil Survey Staff, 1982).

Soil	Classification
Betts	fine-loamy, mixed (calcareous), mesic, Typic Ustorthents
Bonilla	fine-loamy, mixed, mesic, Pachic Haplustolls
Clarno	fine-loamy, mixed, mesic, Typic Haplustolls
Crossplain	fine, montmorillonitic, mesic Typic Argiaquolls
Davison	fine-loamy, mixed, mesic, Aquic Calciustolls
Ethan	fine-loamy, mixed, mesic, Typic Calciustolls
Tetonka	fine, montmorillonitic, mesic, Argiaquic Argialbolls
Worthing	fine, montmorillonitic, mesic, Typic Argiaquolls

Table 2. Soil characteristics affecting spectral reflectance (Kunze, 1982).

Soil Series	Dominant Munsell Colors		Organic Matter %	Drainage Class	Landscape Position	Soil Texture
	Dry	Moist				
Betts	10YR 4/2	10YR 2/2	1 - 3	Well	Shoulder	Loam
Bonilla	10YR 3/1	10YR 2/1	4 - 6	Moderately well	Footslope	Loam
Clarno	10YR 3/1	10YR 2/1	2 - 4	Well	Backslope	Loam
Crossplain	10YR 4/1	10YR 2/1	3 - 6	Somewhat poorly	Footslope	Clay loam
Davison	10YR 4/2	10YR 3/2	2 - 4	Moderately well	Backslope	Loam
Ethan	10YR 4/2	10YR 3/2	1 - 3	Well	Shoulder	Loam
Tetonka	10YR 4/1	10YR 2/1	4 - 8	Poorly	Toeslope	Silt loam
Worthing	10YR 3/1	10YR 2/1	4 - 8	Very poorly	Toeslope	Silty clay loam

Pastures in the study area are dominantly introduced cool season species and native warm season grasses. The cool season grasses were three to 13 cm tall. The warm season species were dormant. Some pastures were grazed.

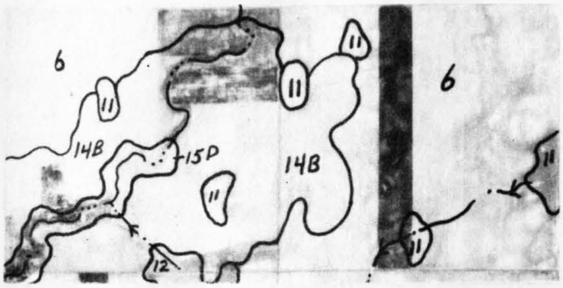
Other areas were planted to small grains. Oats (*Arvena sativa*), wheat (*Triticum aestivum*), and barley (*Hordeum vulgare*) are the most common small grains grown in the area. The seedbed preparation generally consisted of disking or plowing and disking. The amount of crop residue on the surface varied depending on the previous crop and the method of seedbed preparation. Most small grain was 5 to 8 cm tall.

No Land Cover

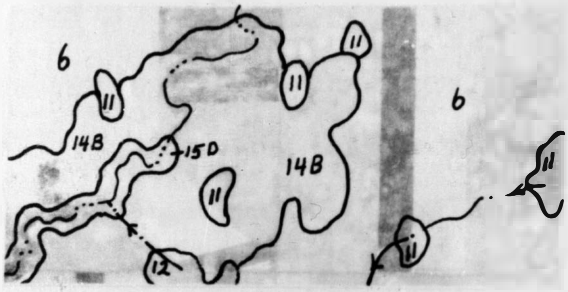
Areas with no land cover the soils are represented by shades of gray on the panchromatic and black and white infrared photographs (Figure 2). Soils that have a higher organic matter content and moisture content such as Crossplain soil in the Clarno-Crossplain-Davison complex and the Bonilla soils in the Clarno-Bonilla complex usually were represented by darker colors than the other soils in these complexes. Soils that have calcium carbonate in the surface layer such as the Davison soils were represented by light tones. Hues in areas with no land cover are dominately green on the color infrared photography because soils reflect relatively large amounts of red light.

The tonal differences among soils were most easily recognized and identified using the color infrared photography because soil reflectance differences in segments of the electromagnetic spectrum

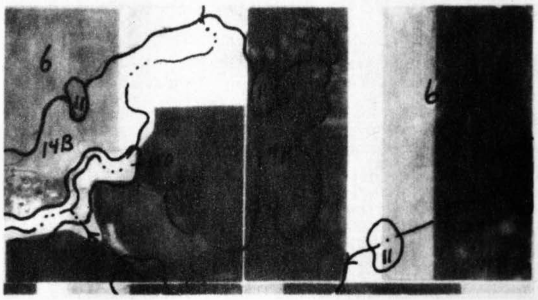
Figure 2. Soils and land cover map of the north one-half of section 20 T. 100 N., R 54 W, using each type of photography.



Panchromatic (600-700 nm)



Panchromatic (500-700 nm)

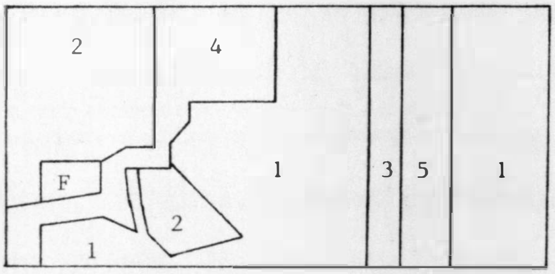


Infrared

Color infrared

SOIL LEGEND

Symbol	Mapping Unit
6	Clarno-Crossplain-Davison complex, 0 to 3 percent slopes
11	Tetonka silt loam
12	Worthing silty clay loam
14B	Clarno-Bonilla loams, 2 to 6 percent slopes
15D	Ethan-Betts loams, 6 to 15 percent slopes



Land Cover Map

LAND COVER LEGEND

Symbol	Land Cover
1	No Cover
2	Crop Residue
3	Alfalfa
4	Pasture
5	Small Grain
F	Farmstead

result in a greater number of color tones present on the color infrared photography than the panchromatic or black and white infrared photography (Table 3). The ease of recognition and identification of tonal difference among soil series was normally greater using the panchromatic (600-700 nm) photography than using the panchromatic (500-700 nm) or black and white infrared photography because contrast among soils was greater using the panchromatic (600-700 nm) photographs than the panchromatic (500-700 nm) or the black and white infrared photographs.

Crop Residue

Crop residue masks the soil surface due to the higher reflectance of crop residue (Figure 2). Crop residue does not mask the background soil patterns as much on the black and white infrared photographs as on the other types of photography. However, the black and white infrared photography, was the least effective in representing tonal differences among soils on areas with no land cover (Table 3).

Recognition and interpretation of soil patterns were generally more difficult in areas covered with crop residue than in areas with no land cover. The tonal differences were most easily recognized and identified using the color infrared photography. The ease of recognition and identification of tonal differences between soils covered with crop residue was slightly greater using the panchromatic (500-700 nm) or the black and white infrared photography than the panchromatic (600-700 nm) photography.

Table 3. Ease of recognition and identification of tonal differences between soil series within mapping unit complexes over the land cover types present.†

	Panchromatic 600–700 nm	Panchromatic 500–700 nm	Black & White Infrared	Color Infrared
	Mean rating			
No Cover (33)	1.5	1.7	2.6	1.0
Crop Residue (23)	3.0	2.6	2.7	1.9
Alfalfa (23)	2.9	3.0	3.7	2.8
Pasture (20)	3.0	3.2	3.9	2.9
Small Grain (27)	2.2	2.3	3.1	1.8

Rating Guide

1 - Easily recognizable and identifiable.
2 - Recognizable and identifiable.
3 - Recognizable and identifiable with difficulty.
4 - Recognition and identification uncertain.

†Number in parenthesis refers to the number of ratings in that mean.

Alfalfa and Pasture

Tones on the aerial photography in areas with growing alfalfa and pasture are a result of the reflection of light from the crop canopy in the wavelengths detected by each type of film (Figure 2). Dark colors on photography sensitive to light in the visible portion of the spectrum are a result of absorption by chlorophyll in the visible part of the spectrum (Gates et al., 1965). The panchromatic (600-700 nm) photography has darker colors for the same soils with growing alfalfa than the panchromatic (500-700 nm) due to the stronger absorption in the red part of the spectrum and than in the green part of the spectrum. Soils with more actively growing vegetation such as the Crossplain soils in the Clarno-Crossplain-Davison complex are repre-sented on the panchromatic photography as darker tones than soils with less actively growing vegetation such as on the Clarno and Davison soils. Soils with actively growing alfalfa or pasture are represented by a lighter tones on the black and white infrared photography than soils with alfalfa or pasture under more stress due to reflectance of near infrared radiation by actively growing vegetation (Gates et al., 1965). Soils with actively growing alfalfa or pasture appear more red on the color infrared photography than soils with these crops under more stress. The reddish colors on the color infrared photograhy are a result of high reflection of near-infrared radiation (Fritz, 1967).

Recognition and identification of soil patterns in areas of growing alfalfa or pasture was more difficult on soils growing alfalfa or pasture than in areas of soils covered with crop residue or with no land cover (Table 3). The panchromatic (600-700 nm), the panchromatic (500-700 nm), and the color infrared photography appeared to be more useful than the black and white infrared photography in the recognition and identification of tonal differences between soil series within mapping unit complexes in areas of growing alfalfa and pasture. The black and white infrared photographs had little contrast among soils. The color infrared photography was slightly more useful in identifying soil patterns than the panchromatic (600-700 nm) or the panchromatic (500-700 nm) photographs due to the greater number of color tones represented on the color infrared photography.

Small Grain

Soils with growing small grain had slightly darker tone than the same soils with no land cover on the panchromatic photography due to absorption (Figure 2) by chlorophyll in the visible portion of the spectrum. On the color infrared photographs soils with growing small grain appear similar to areas of crop residue. This may be due partially to crop residue normally left on the surface when planting small grain. The light red color due to greater reflectance in the near-infrared portion of the spectrum in areas of the Crossplain soil of small grain on the Crossplain soil than on the Clarno and Davison soils.

The color infrared was most useful in recognition and identification of tonal differences among soil series in fields planted to small grain (Table 3). The panchromatic (600-700 nm) and panchromatic (500-700 nm) were slightly less useful than the color infrared photographs in the recognition and identification of soil patterns.

Recognition and identificatin of soils with growing small grain was difficult to uncertain using the black and white infrared photography. The color infrared photography was more useful than the other three types of photography due to representation of soil and plant reflectance difference of segments of the electromagnetic spectrum as different hues, values, and chromas resulting in a greater number of color tones.

CONCLUSIONS

Panchromatic (600–700 nm), panchromatic (500–700 nm), black and white infrared and color infrared photographs were compared to evaluate their usefulness in distinguishing tonal differences between soil series components of complex mapping units.

The color infrared photography most clearly emphasized tonal differences among the soil series components of complex mapping units over the land cover types tested due to incorporaton of the reflectance information from three segments of the spectrum as separate color codes on one photograph.

Color infrared photography would be useful in improving soil mapping quality due to greater tonal contrast among soil series on the color infrared photography than on the panchromatic or black and white infrared photography. Color infrared photography would also be most useful in determining the composition of complex mapping units over a variety of land cover types.

REFERENCES

Bowers, S. A. and R. J. Hanks. 1965. Reflection of radiant energy from soils. Soil Science 100:130-138.

Benson, L. A. 1973. Reflectance Measurements for the Detection and Mapping of Soil Limitations. M. S. Thesis, South Dakota State University.

Eastman Kodak Company. 1970. Kodal Wratten Filters for Scientific and Technical Use. Kodak Publication B-3, Rochester, New York.

Eastman Kodak Company. 1972. Kodak Aerial Films and Photographic Plates. Kodak Publication M-61, Rochester, New York.

Evans, R. 1948. An Introduction to Color. Wiley. New York.

Flint, R. F. 1955. Pleistocene Geology of Eastern South Dakota. U. S. Dept. of Interior Geological Survey Professional Paper 262, Washington, D. C.

Frazee, C. J., R. L. Carey, and F. C. Westin. 1972. Utilizing remote sensing data for land use decisions for Indian land in South Dakota. Proceedings of the 8th Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp. 375-391.

Fritz, N. L. 1967. Optimum methods for using infrared sensitive color film. Photogrammetric Engineering 33:1128-1138.

Gates, D. M., H. J. Keegan, J. C. Schleter, and V. R. Weidner. 1965. Spectral properties of plants. Applied Optics 4:11-20.

Kunze, B. O. 1982. Soil Survey of Turner County, South Dakota. Soil Conservation Service, U. S. Dept. of Agriculture, Wasington, D. C.

Soil Survey Staff. 1975. Soil Taxonomy -- a basic system of soil classification for making and interpreting soil survey. Soil Conservation Service, U. S. Dept. of Agriculture, Agricultural Handbook No. 436, Washington, D. C.

Soil Survey Staff. 1982. Soil Series of the United States, Puerto Rico, and the Virgin Islands. Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C.